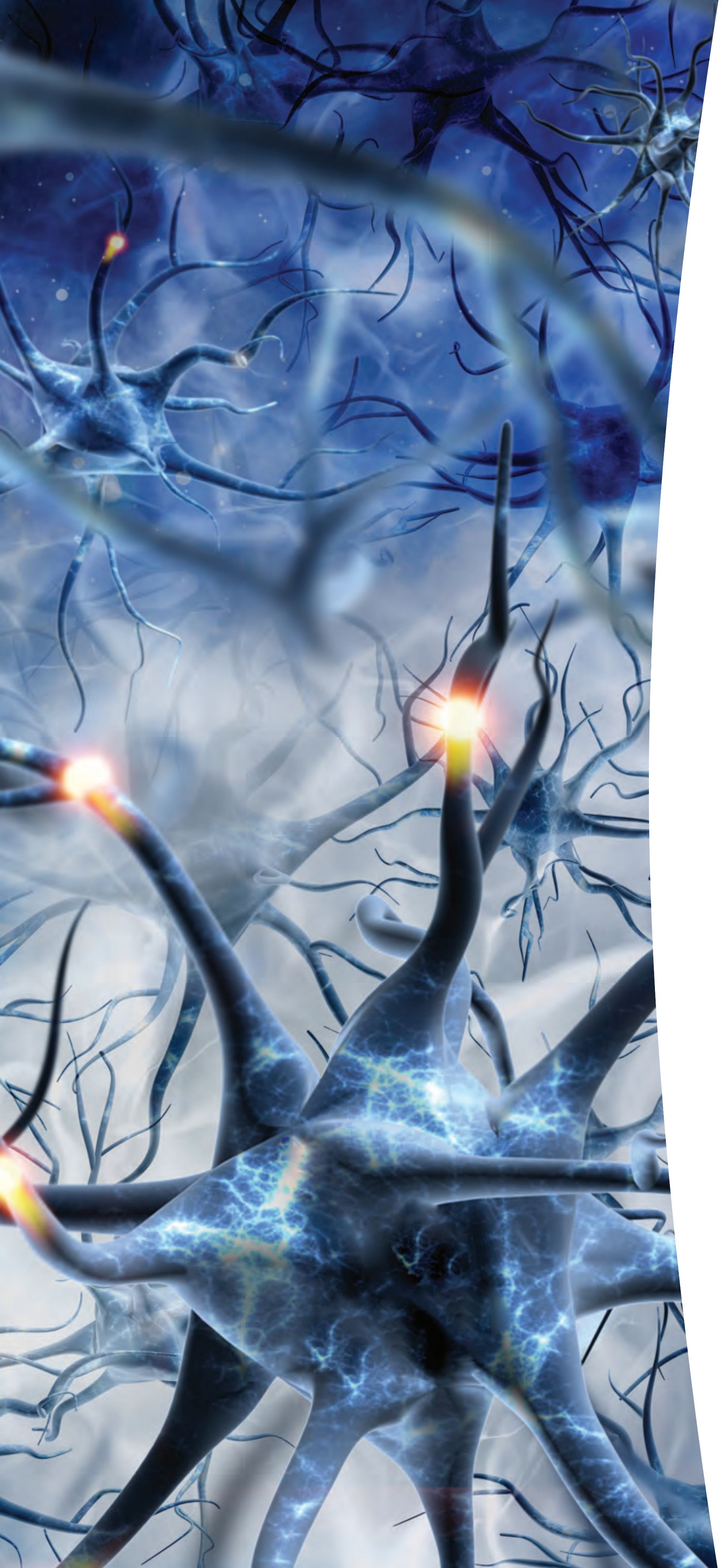

Chapter 2

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The **Biology** *of* **Behavior**

Until fairly recently, both laypersons and psychologists viewed behaviors such as thinking, feeling, and remembering as something more than complex interactions between cells in the brain. For example, the mind was thought to consist of nonphysical entities such as a spirit or soul. However, most researchers are now convinced that the mind consists of a collection of processes that will eventually be explained in terms of molecular events in the brain. In fact, neuroscientists are making remarkable progress toward this end.

This chapter provides a very broad overview of what we know about the biology of behavior. Biological structures including individual neurons, the central and peripheral nervous systems, and the endocrine systems are examined to see how they influence or regulate behaviors. We begin with a look at the nervous system.

2.1 Overview of the Nervous System: Organization and Function

All of our activities—sensing, perceiving, moving, feeling, thinking, and remembering—depend on the functioning of our nervous systems. Although the brain is the hub of the **nervous system**, it is by no means the sole component. The nervous system of humans and all other vertebrates (organisms with a spinal cord encased in bone) consists of two major parts: the central nervous system (CNS) and the peripheral nervous system (PNS). The PNS has two subdivisions: the somatic and autonomic nervous systems. These components are all shown in Figure 2-1. We shall examine each of these parts in depth after a preliminary overview.

The **central nervous system** (**CNS**) consists of the brain and the spinal cord, which are the most protected organs of the body. Both are encased in bones and surrounded by protective membranes called meninges. The CNS plays a central role in coordinating and integrating all bodily functions. It acts as an intermediary between the stimuli we receive and our responses to those stimuli. For example, if your bare foot comes in contact with something hairy and wiggly when you put on a shoe, a message of alarm will travel through nerves in your legs, enter your spinal cord, reach your brain, and trigger a rapid response.

In the situation just described, the CNS acts as a processor of incoming and outgoing messages; however, the brain also sends commands directly to various parts of our bodies without first receiving an incoming stimulus. For instance, the decision to put on your shoes in the first place may have been the result of a decision to go outdoors—a decision that was unrelated to any immediate stimulus.

Our brains can also send commands to glands or organs. If you are dressed too warmly in an overheated classroom, for example, you will probably begin to perspire. This response is mediated by the hypothalamus, a small structure in the brain that serves many critical functions—including temperature regulation. When our bodies become too hot, the hypothalamus signals our sweat glands to perspire, which helps us regulate body temperature.

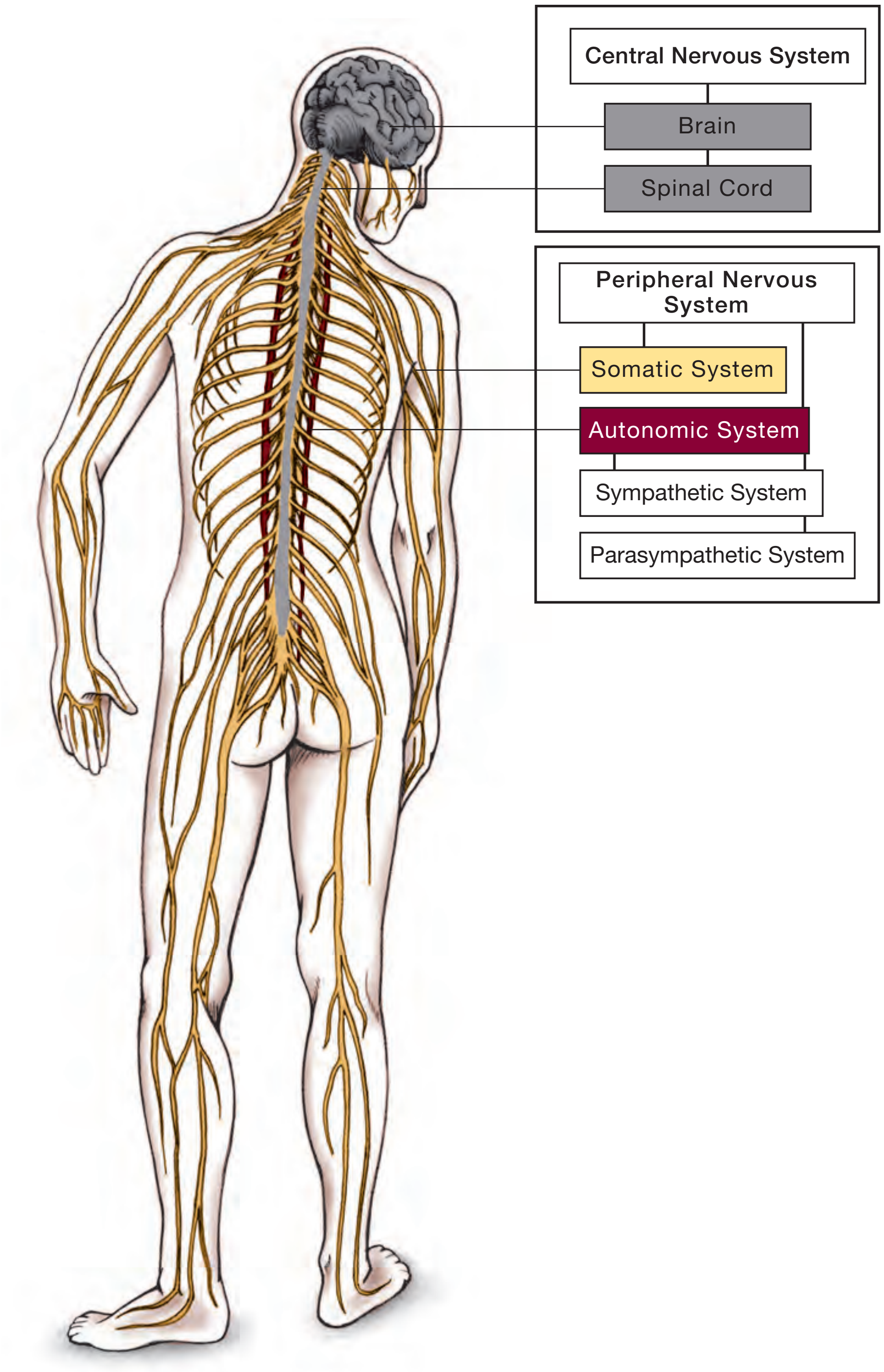
Although the CNS occupies the commanding position in the nervous system, it could neither receive stimuli nor carry out its own directives without the **peripheral nervous system** (**PNS**). The peripheral nervous system transmits messages to and from the central nervous system. It is subdivided into two functional parts, the somatic nervous system and the autonomic nervous system—both of which are discussed later in this chapter. Before looking further at both the central and peripheral nervous systems, it is helpful to have an understanding of the building blocks that are the basis of the entire nervous system. The individual cells that make up the nervous system are called neurons.

Nervous System A network of specialized cells called neurons and glia that coordinate action and transmit signals between different parts of the body; consists of the central nervous system and the peripheral nervous system

Central Nervous System (CNS) The part of the nervous system that consists of the brain and the spinal cord

Peripheral Nervous System (PNS) The part of the nervous system that transmits messages to and from the central nervous system and that consists of the somatic nervous system and the autonomic nervous system

Figure 2-1 Divisions of the Nervous System



2.2 Neurons: Basic Units of the Nervous System

Our bodies are made up of trillions of living cells, including blood cells, skin cells, muscle cells, and bone cells. The cells of particular interest in this chapter are the cells of the nervous system called **neurons**, which are the basic units of the brain and the rest of the nervous system. They vary in shape, size, and other characteristics according to their location and function in the nervous system. The brain, for instance, contains the most concentrated mass of neurons. It is impossible to say how many neurons it contains, but estimates range between 100 and 200 billion. Although this is an extraordinarily large number, sheer number alone does not account for the extreme complexity of the brain. Neurons throughout the nervous system are supported and protected by an even larger number of non-neuronal cells called **glia**. Although glial cells do not transmit electrical signals, they do provide essential functions to surrounding neurons. Several of these are discussed below.

There are three major classes of neurons. One class, called **sensory** or **afferent neurons**, carries messages to the CNS from receptors in the skin, ears, nose, eyes, and so forth. The brain and sometimes the spinal cord interpret these messages and send appropriate responses through a second type of neurons called **motor** or **efferent neurons**, which lead to muscles and glands. A third class of neurons, **interneurons**, resides only within the central nervous system. Since motor and sensory neurons rarely communicate directly, interneurons play a critical intermediary role. Without these connecting neurons, sensory messages would never result in the appropriate bodily responses. Interneurons also communicate directly with each other.

2.2a Neuron Structure

Although neurons vary in size, shape, and function, they share four common structures: the cell body, the dendrites, the axon, and the terminal buttons (see Figure 2-2).

The Cell Body or Soma

The **cell body**, or soma, is the largest part of the neuron. It contains structures that handle metabolic functions; it also contains the nucleus, which holds genetic information encoded in the cell's DNA. The cell body can receive impulses from other neurons, although the cell body is not the primary receptor.

The Dendrites

Neurons typically receive neural messages at one end and pass them on at the other end. The part of the neuron that receives most transmitted signals is a collection of fibers called **dendrites**, which extend out from the cell body like branches of a tree. (The word *dendrite* comes from the Greek word for tree.) Dendrites may receive information from a few to thousands of the surrounding neurons. The more extensive the neuron's network of dendrites, the more connections can be made with other neurons. (Interneurons in the brain typically contain far more dendritic fibers than neurons in the spinal cord, or the peripheral nervous system.) Signals received by the dendrites are passed on to the cell body, which in turn passes them through the axon.

Neuron Type of cell that is the basic unit of the nervous system; typically consists of a cell body, dendrites, and an axon; transmit messages to other neurons and to glands and muscles throughout the body

Glia Nonneuronal cells that provide support and protection for neurons throughout the nervous system (The name *glia* comes from the Greek term for "glue.")

Sensory Neuron Neuron or nerve cell that carries messages to the CNS from receptors in the skin, ears, nose, eyes, and other receptor organs; also known as *afferent neuron*

Motor Neuron Neuron that transmits messages from the central nervous system to muscles or glands; also known as *efferent neuron*

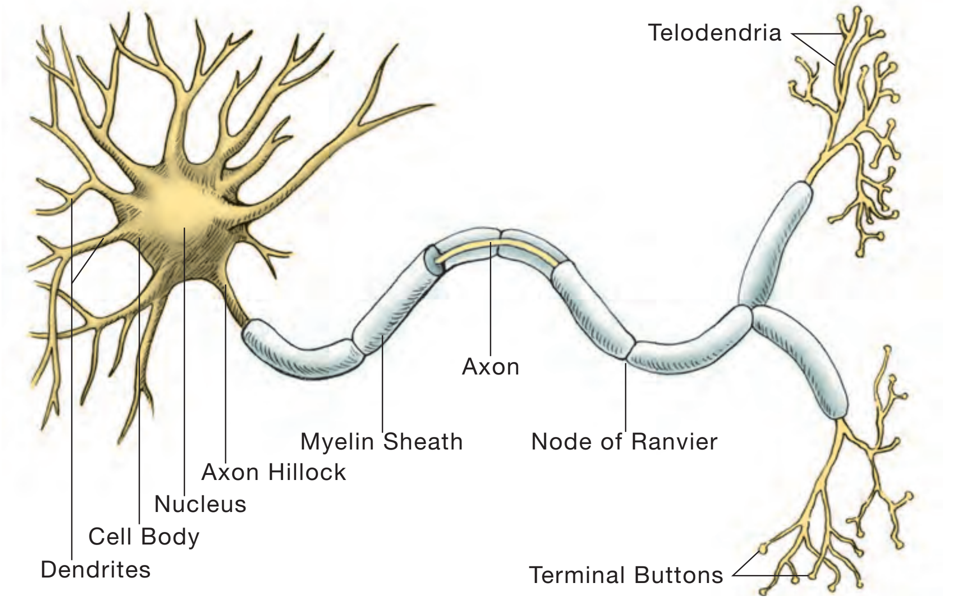
Interneuron Neuron of the central nervous system that functions as an intermediary between sensory and motor neurons

Cell Body The largest part of a neuron, containing the nucleus and structures that handle metabolic functions

Dendrite Branchlike extensions from a neuron with the specialized function of receiving messages from surrounding neurons

Figure 2-2 Neuron Structure

Neural messages from surrounding neurons are received by the dendrites and then passed down to the cell body, the portion of the neuron in which metabolic functions takes place. The neural signal then moves along the axon, the transmitting fiber of the neuron. Terminal buttons at the end of the axon release chemicals called neurotransmitters that activate adjacent neurons, thereby allowing the messages to continue. This activation can take the form of either excitation or inhibition. Neural excitation facilitates the transmission of neural messages, while neural inhibition retards or prevents the transmission of these signals.



The Axon

The **axon** is a slender, extended fiber that takes a signal from the cell body at a point called the axon hillock and transmits it along its entire length, which may range from two or more feet in spinal cord and PNS neurons to a tiny fraction of an inch in brain neurons. The axon may divide into two or more major branches called *collaterals*, thereby increasing its capacity to communicate with other neurons. Axons may be myelinated or unmyelinated. Myelin is a type of glial cell that wraps around the axon, providing it with insulation. Most peripheral axons are myelinated, and most (but not all) of the axons in the brain are unmyelinated. Myelin serves both to insulate the axon, much like insulation on a wire, and to increase the speed of conduction along the axon. It is myelin that gives brain tissue, which is normally grayish brown, a white color (white vs. gray matter).

Axon Extension of a neuron that transmits an impulse from the cell body to the terminal buttons on the tip of the axon

Terminal Buttons Swollen bulblike structures on the end of a neuron's axon that release chemical substances known as neurotransmitters

The Terminal Buttons

The transmitting end of the axon consists of small bulblike structures known as terminal buttons. The **terminal buttons** store and release chemical substances (called neurotransmitters) that enable nerve impulses to cross from one neuron to adjacent neurons. In the next section, we will look at this complex process.

2.2b Neural Transmission

People often think of the nervous system as a vast, complex network of interconnected wirelike structures. However, the multitudes of neural circuits or pathways within the central nervous system are not at all like electric wires. Instead of a continuous filament, these circuits are made up of perhaps hundreds of thousands of individual neurons. In order for a message to travel from neuron to neuron, it must move from the terminal buttons at the end of one neuron's axon to the dendrites or cell body of an adjacent neuron. The process by which impulses are transmitted in the CNS is not just electrical, as it is in the wiring system of a house; it also involves chemical substances called neurotransmitters. The entire process is called *neural transmission*.

Within the peripheral nervous system, messages are transmitted along the extended axonal fibers of both motor and sensory neurons that are contained within bundles of neural fibers called *nerves*. These fibers extend as continuous structures from sensory receptors or muscles to the CNS. For example, a sensory message from a pain receptor in the skin of your finger is transmitted along a single axonal fiber that extends the length of your arm to a point at which it enters the spinal cord and transfers its message to an interneuron.

BVT Lab

Visit **www.BVTLab.com** to explore the student resources available for this chapter.

2.2c Neuron Electrical Activity

Like all other cells, a neuron is surrounded by a membrane. This membrane acts as a kind of skin that permits the cell to maintain an internal environment different from the fluid outside the membrane. On both sides of the cell membrane are many particles called ions, which carry either a positive or a negative electrical charge. Ions that are particularly important in electrical conduction are negatively charged organic ions (An^-) and chloride ions (Cl^-), and positively charged sodium ions (Na^+) and potassium ions (K^+). If the cell membrane did not act as a barrier, these ions would be equally distributed both inside and outside of the neuron. However, some charged particles, such as the negative organic ions, do not pass through the cell membrane to the surrounding fluid. The membrane is only semipermeable to other ions. For instance, sodium and potassium ions pass through only when ion channels or "gates" are open for them.

Resting Potentials

Thus, the negative and positive charges are unequal on either side of the membrane, and its interior has a negative electrical potential with respect to its exterior. This phenomenon is due primarily to a high concentration of positively charged sodium ions outside the membrane and more negatively charged organic ions on the inside. A neuron at rest (that is, not transmitting a nerve impulse) contains a net negative charge of about –70 millivolts (70/1,000 of a volt) relative to the outside environment. The membrane is said to be in a polarized state when the neuron is at rest.

This differential charge gives the resting neuron a state of potential energy known as the **resting potential**. In other words, it is in a constant state of readiness to be activated by an impulse from an adjacent neuron. Maintaining this resting potential allows the neuron to store the energy that it utilizes when it transmits an impulse. The resting potential is maintained because the membrane is impermeable to the positively charged sodium (Na^+) ions concentrated on the outside of the neuron (see Figure 2-3).

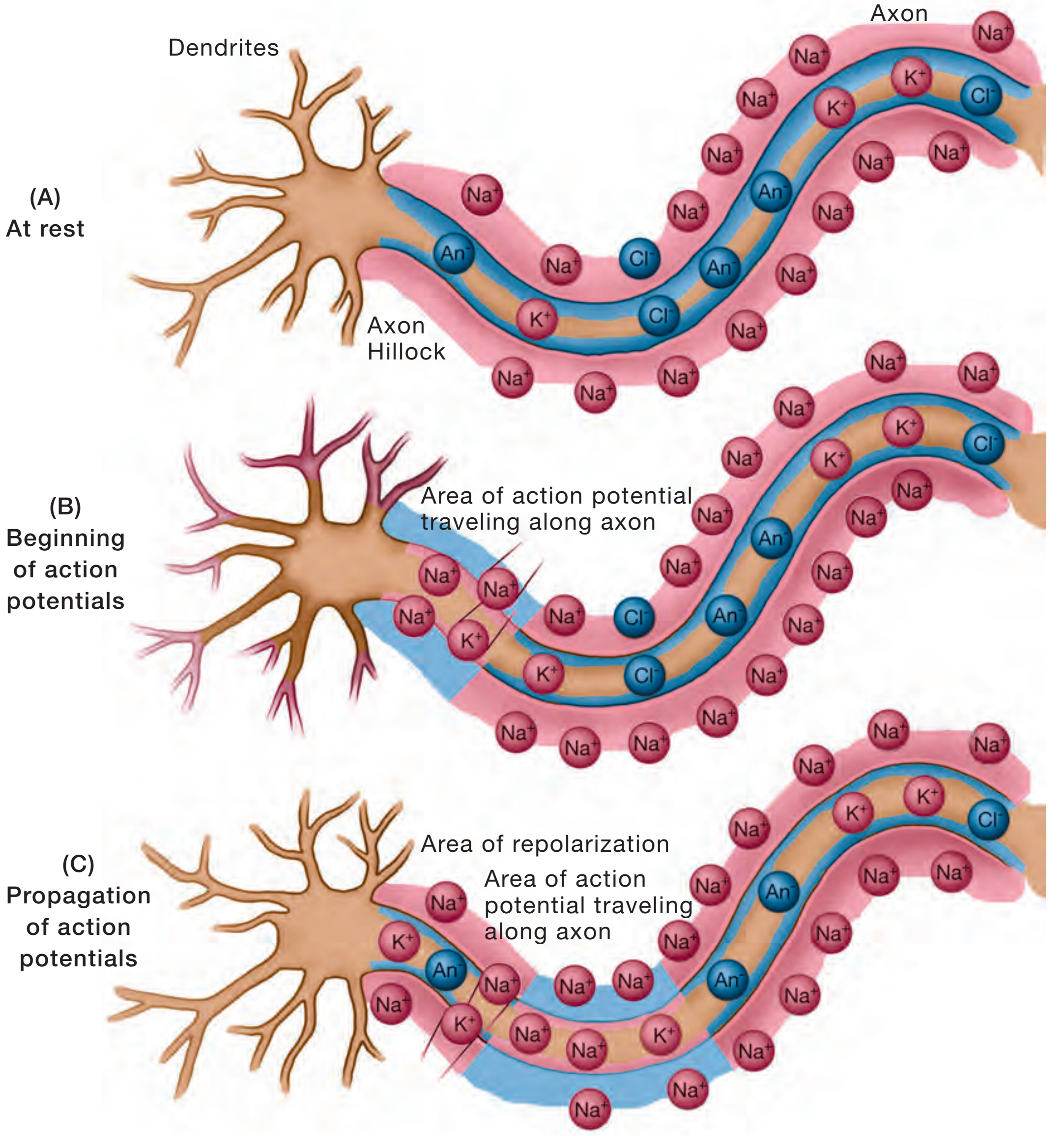
Resting Potential State in which a neuron is not transmitting a nerve impulse (A neuron in this state has a net negative charge relative to its outside environment, and this state of potential energy prepares it to be activated by a signal from an adjacent neuron.)

Figure 2-3 Neuron Electrical Activity

A. Neuron at rest. Resting membrane potential is maintained by distribution of charged ions on either side of the membrane.

B. Initiation of action potential. Action potential is initiated at axon hillock by movement of sodium (Na^+) ions to inside of cell.

C. Movement of action potential. Action potential moves (propagates) along axon as Na^+ ions enter cell. After an action potential occurs, membrane potential is restored by movement of both potassium (K^+) and sodium (Na^+) ions to their resting potential positions.



Graded Potentials

The resting potential is disturbed when an impulse is received from another neuron. This disturbance is referred to as a **graded potential**, and its strength varies with the intensity of stimulation. If we were to measure the charge on the axon during a graded potential, we would observe a change from –70 millivolts to perhaps –60 millivolts, depending on the amount of stimulation the cell receives. A graded potential by itself is of little consequence. However, when several graded potentials occur simultaneously or in rapid succession, together they may be sufficient enough to depolarize the neuron to a threshold value (the minimum voltage change sufficient to activate a response) of about –55 millivolts.

The determination of whether or not a graded potential is sufficient to bring the axon to its threshold level is made at the **axon hillock**, a specialized region of the cell body near the base of the axon (refer back to Figure 2-2). Like a tiny computer, the axon hillock combines and totals all the graded potentials that reach it. If the sum of these graded potentials reaches a sufficient magnitude or threshold, a sudden depolarization begins at the axon hillock. This depolarization is referred to as an action potential.

Action Potentials

An **action potential** is initiated when the axon is depolarized to its threshold level (approximately –55 millivolts). When the membrane reaches this threshold level, a sudden complete depolarization results—that is, the axon goes from about –55 millivolts to approximately +40 millivolts. This rapid depolarization is the result of the membrane changing its permeability to sodium (Na^+) ions. When the membrane is no longer impermeable to Na^+, it enters the cell, bringing the charge on the inside of the membrane to a positive value (about +40 millivolts). Some potassium ions begin to leave the axon at this time because the electrical gradient inside the axon becomes weakened as sodium ions enter. However, the number of potassium ions that leave the inside of the axon is far outweighed by the number of sodium ions that enter.

The change in permeability to Na^+ is extremely brief, and the closing of the Na^+ gates and the rapid expulsion of Na^+ from within the axon quickly restore the resting potential. Sodium ions are repelled because of the positive charge now inside the membrane. As sodium ions leave, the charge across the membrane returns to its resting state. In fact, an excess of sodium outflow briefly hyperpolarizes the membrane. This complete process for an action potential takes about a millisecond (1/1,000 of a second).

The action potential is an electrical signal that flows (or propagates) along the entire surface of the axon to the terminal button. Once the action potential reaches the terminal button, it initiates the release of neurotransmitter substances that carry the message to adjacent neurons.

The All-or-None Law

Unlike the graded potential, the strength of an action potential does not vary according to the degree of stimulation. Once a nerve impulse is triggered within an axon, it is transmitted the entire length of the axon with no loss of intensity. Partial action potentials or nerve impulses do not occur; thus, an axon is said to conduct without decrement. Because of this, the nerve impulse in the axon is said to follow the **all-or-none law**: If the sum of the graded potentials reaches a threshold, there will be an action potential; if the threshold is not reached, however, no action potential will occur.

Graded Potential Voltage change in a neuron's dendrites that is produced by receiving a signal from another neuron or neurons

Axon Hillock A specialized region of the cell body near the base of the axon

Action Potential Electrical signal that flows along the surface of the axon to the terminal buttons, initiating the release of neurotransmitters

All-or-None Law An action potential will be passed through a neuron's axon as long as the sum of the graded potentials reaches a threshold. The strength of an action potential does not vary according to the degree of stimulation. See also *graded potential.*

According to the all-or-none law, a neuron fires at only one level of intensity. How, then, is it possible to distinguish between different levels of stimulus intensity—for instance, a loud noise and a soft sound, or a light or heavy touch? Consider this question before reading on.

The answer to our question lies in the fact that, even though a single neuron's impulse level is always the same, two important variables may still change the number of neurons affected by an impulse and the frequency with which neurons fire. Very weak stimuli may trigger impulses in only a few neurons, whereas very strong stimuli may cause thousands of neurons to fire. The frequency in which neurons fire can also vary greatly, from fewer than one hundred times per second for weak stimuli to as often as one thousand times per second for strong stimuli. Thus, the combination of how many neurons fire and how often they fire allows us to distinguish different intensities of stimuli.

The speed with which an impulse travels through a neuron varies with the properties of the axon, ranging from less than 1 meter per second to as fast as 100 meters per second (roughly 224 miles per hour). At least two important factors affect speed. One is the resistance to current along the axon; there is an inverse relationship between resistance and impulse speed, so that speed is reduced as resistance increases. Resistance is most effectively decreased by an increase in axon size, which helps explain why large axons, such as those in PNS neurons, tend to conduct impulses at a faster rate than do small axons.

However, if the nervous system had to depend only on axon size to transmit impulses quickly, there would not be enough room in our bodies for all the large axons we would need. Fortunately, a second property also helps to increase the speed of transmission of nerve impulses. Glial cells wrap around some axons, forming an insulating cover called a **myelin sheath**. One type of glial cell, the oligodendrocyte, forms the myelin within the CNS. In the PNS, the insulating sheaths are built from another type of glial cell known as the Schwann cell. Between each glial cell the axon membrane is exposed by a small gap called a **node of Ranvier**, as shown in Figure 2-2.

In these myelinated neurons, nerve impulses do not travel smoothly down the axon. Instead, they jump from node to node, in a process called *saltatory conduction* (from the Latin *saltare*, meaning to leap). Saltatory conduction is so efficient that a small myelinated axon can conduct a nerve impulse just as quickly as an unmyelinated axon thirty times larger. Because myelin plays such a critical role in the nervous system, it follows that the effects of certain diseases (such as *multiple sclerosis [MS]*) that involve progressive breakdown in these insulating sheaths can be devastating. In MS, the loss of myelination may short-circuit or delay the transmission of signals from the brain to the muscles of the arms and legs. As a consequence, a person with MS often experiences a weakness or loss of control over the limbs.

Myelin Sheath Insulating cover around some axons that increases a neuron's ability to transmit impulses quickly; made of specialized cells called *glial cells*

Node of Ranvier Small gap or exposed portion of the axon of a neuron between the glial cells that form the myelin sheath

Synapse Includes the synaptic gap and a portion of the presynaptic and postsynaptic membranes that are involved in transmitting a signal between neurons

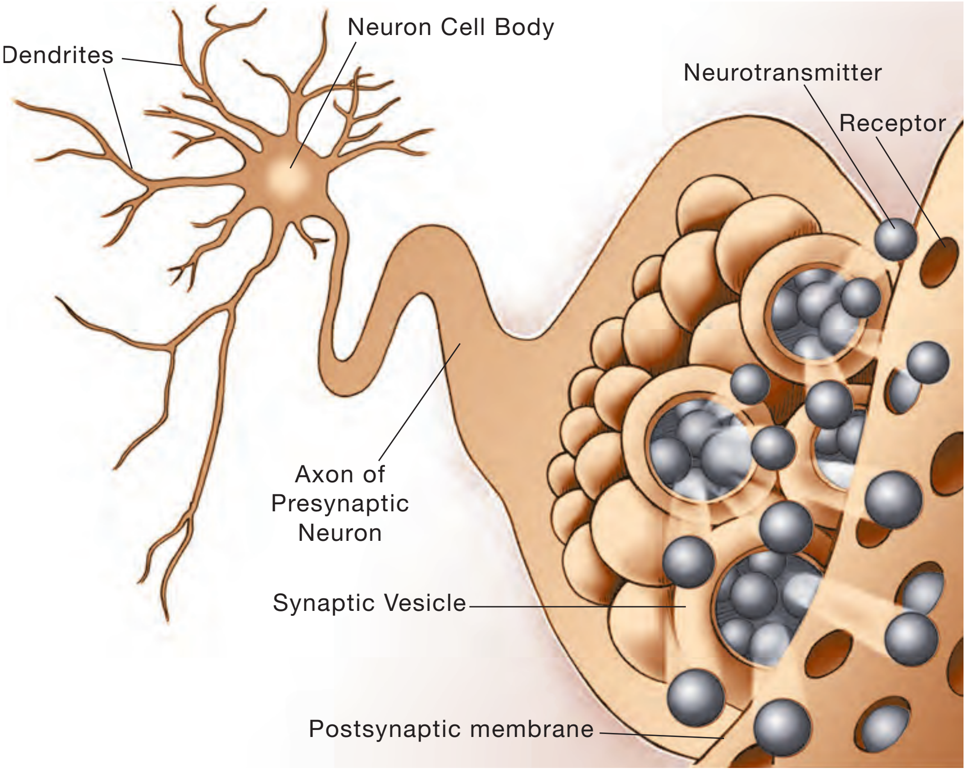
2.2d Neurotransmitters and the Synapse

The transmission of an electrical impulse from one end of a neuron to the other provides only a partial explanation of how messages are transmitted. When an electrical nerve impulse reaches the end of an axon, it cannot flow directly into other neurons. This is because there is a space between neurons known as the synaptic gap. The space is minuscule—generally no more than five-millionths of an inch across—but the electrical impulse does not bridge it alone. A chemical process is necessary in bridging the synaptic gap. Figure 2-4 illustrates a **synapse**, which includes the membrane on the terminal button (the presynaptic membrane), the synaptic gap, and the membrane on the dendrite or receiving neuron (the postsynaptic membrane).

Many years ago, some scientists speculated that impulses were transmitted from neuron to neuron when something like an electric spark jumped the synaptic gap. We

Figure 2-4 Synapse

An active synapse with the neurotransmitter being released into the synaptic gap



now know that this explanation is incomplete. Neurons communicate primarily through the release of chemicals. These chemical messengers, called **neurotransmitters**, are contained within tiny sacs in the axon terminal buttons called synaptic vesicles. Far less common is the electrical synapse, in which an electrical potential is conducted from one neuron to the next because of a tight junction between them. These rare electrical synapses will not be discussed here.

Steps in Neural Transmission

When the axon fires, the action potential travels along the axon to the terminal button. When it arrives at the terminal button, the membrane there changes its permeability to another ion, calcium (Ca^{++}). Calcium then enters the terminal button and allows the synaptic vesicles to migrate to the presynaptic membrane, where they release their contents into the synapse. The total amount of neurotransmitter released depends on how much Ca^{++} enters the terminal button. More intense stimulation produces a greater frequency of action potentials, which in turn allows more Ca^{++} to enter, thus increasing the amount of neurotransmitter released.

Neurotransmitter Chemical substance produced and secreted by neurons that causes a change in the receiving neuron's resting potential

Excitatory and Inhibitory Synaptic Events

The postsynaptic membrane of the receiving neuron contains specialized receptor sites that respond to a variety of neurotransmitters, which act on these receptor sites to produce a rapid change in the permeability of the postsynaptic membrane. Depending on the receptor site and the type of neurotransmitter, this change in permeability can either excite or inhibit action potentials in the receiving neuron.

In simplified terms, neurotransmitters exert their effects by opening gates or channels in the postsynaptic membrane, letting ions of one kind or another pass through. If positively charged sodium ions enter, the membrane is excited or depolarized, and graded potentials are caused. Neurotransmitters that cause these changes are called excitatory neurotransmitters, and their effects are referred to as **excitatory postsynaptic potentials**, or **EPSPs**. Conversely, if positively charged potassium ions pass to the outside of the postsynaptic membrane, or negatively charged chloride ions enter, the membrane is inhibited and the graded potential results in making the membrane more negative (a process called hyperpolarization). Neurotransmitters that act in this way are called inhibitory neurotransmitters, and their effects are called **inhibitory postsynaptic potentials**, or **IPSPs**.

Since hundreds or even thousands of axon terminals may form synapses with any one neuron, EPSPs and IPSPs may be present at the same time. The combination of all these excitatory and inhibitory signals determines whether or not the receiving neuron will fire. For an action potential to occur, EPSPs must not only predominate, they must do so to the extent of reaching the neuron's threshold. To prevent this from happening, there needs to be a sufficient number of IPSPs present to prevent the algebraic sum of EPSPs and IPSPs from reaching the threshold of depolarization.

Some neurotransmitters seem to be exclusively excitatory or inhibitory; others seem capable of producing either effect under different circumstances. When transmitters have both capabilities, the postsynaptic receptor site determines what the effect will be. Thus, these neurotransmitters may have an inhibitory effect at one synapse and an excitatory effect at another.

Neurotransmitters interact with receptors on the postsynaptic cell membrane to change its electrical potential. If the change is sufficient to depolarize the cell membrane, a graded potential is initiated, thus beginning the cycle outlined earlier in Figure 2-3.

Excitatory Postsynaptic Potentials (EPSPs) Effects that occur when excitatory neurotransmitters cause a depolarizing graded potential to occur on the dendrite or cell body of a receiving neuron, making the receiving neuron more likely to fire

Inhibitory Postsynaptic Potentials (IPSPs) Effects that occur when inhibitory neurotransmitters cause a hyperpolarizing graded postsynaptic potential on a receiving neuron, making the receiving neuron less likely to fire

Neurotransmitter Breakdown and Reuptake

What keeps the supply of neurotransmitters from being exhausted? There are several answers to this question. First, the raw materials used in the manufacture of neurotransmitters are constantly being replenished by the cell body. Second, some neurotransmitters are broken down by enzyme action once they have accomplished their function. Their breakdown products then re-enter the terminal buttons to be recycled for further use. Third, in many cases the transmitter substance is retrieved intact in a process called *reuptake*. The breakdown and reuptake processes, which are essential for normal neuronal functioning, can be influenced by a number of drugs. For example, drugs such as amphetamine and cocaine inhibit the reuptake of several neurotransmitters, resulting in heightened alertness and activity. Finally, neurons contain regulatory mechanisms that prevent depletion and regulate their sensitivity to neurotransmitters.

Table 2-1 Chemicals Known to Be Major Neurotransmitters

Neurotransmitter Effects	Location	Functions
Acetylcholine (ACh) Excitatory	Cortex, spinal cord, target organs activated by parasympathetic nervous system	Excitation in brain. Either excitation or inhibition in target organs of PNS. Involved in learning, movement, memory.
Norepinephrine (NE) Excitatory	Spinal cord, limbic system, cortex, target organs of sympathetic nervous system	Arousal of reticular system. Involved in eating, emotional behavior, learning, memory.
Dopamine (DA) Inhibitory	Limbic system, basal ganglia, cerebellum	Involved in movement, emotional behavior, attention, learning, memory, and reward.
Serotonin (SE) Inhibitory	Brain stem, most of the brain	Involved in emotional behavior, arousal, and sleep.
Gama-amino-butyric acid (GABA) Inhibitory	Most of the brain and spinal cord	Involved in regulating arousal; major inhibitory neurotransmitter in brain.
Endorphins Inhibitory	Spinal cord, most of the brain	Functions as a natural analgesic for pain reduction; involved in emotional behavior, eating, and learning.
Glutamate Excitatory	Brain and spinal cord	Major excitatory neurotransmitter in the brain. Involved in learning.

Identifying Neurotransmitter Substances

As much as scientists know about the electrochemical process of transmitting nerve impulses, the neurotransmitters themselves have been hard to identify because they often occur in very small quantities. Table 2-1 presents a list of several important substances known to be neurotransmitters, as well as the functions they are thought to perform. For a substance to be considered a neurotransmitter it must meet the following criteria: (a) It must be contained in the axon terminal buttons, (b) it must be released into the synapse when the neuron fires, and (c) it must cause a postsynaptic effect after it interacts with the receptor.

Neurotransmitter Substances

What are some of the chemicals that are known to serve as neurotransmitters? Although the list of substances so far identified as neurotransmitters is quite large, we will discuss a few neurotransmitters that are well understood and play important roles in our behavior.

Acetylcholine

Acetylcholine (ACh) was the first neurotransmitter discovered. It plays an important role in motor movement because it is the neurotransmitter released from motor neurons onto muscle fibers to make them contract. In addition, acetylcholine appears to be involved in both learning and memory. Several toxins such as botulism, nerve gas, and black widow spider venom interfere with acetylcholine transmission and produce paralysis in their victims. A common disorder that involves acetylcholine is Alzheimer's disease, which involves a degeneration of acetylcholine neurons in the brain. Although the causes of Alzheimer's disease are not well understood, and at the present there is no cure, drugs that increase the availability of acetylcholine are being used to treat the symptoms of this debilitating disease (Tabet, 2006; Hernandez & Dineley, 2012).

Acetylcholine (ACh) The neurotransmitter that is released from motor neurons onto muscle fibers to make them contract; also involved in learning, memory, and cognition

Norepinephrine

Norepinephrine is distributed throughout the central and peripheral nervous systems. It is important in emotional arousal, stress, and perhaps learning and memory. Norepinephrine is a major excitatory neurotransmitter in the brain. Deficiencies in norepinephrine activity are linked to depression and attention deficit disorders (Arnsten & Pliszka, 2011; Haenisch, Bilkei-Gorzo, Caron, & Bönisch, 2009).

Dopamine

Dopamine is located primarily in the brain; it is involved with the initiation of motor movement, attention, and learning and memory. In addition, the dopamine system mediates reward and pleasure, and it is the substance of addiction. We will see later in this chapter that all addictive drugs increase the activity of the dopamine system. Deficiencies in dopamine result in Parkinson's disease, which is a severe motor disorder. Parkinson's disease is, at the present, most effectively treated with a drug (l-DOPA) that is converted into dopamine in the brain (Hurley & Jenner, 2006; Nandhagopal et al., 2011; Volkow et al., 2007). In addition, the major psychotic disorder, schizophrenia, appears to be associated with an excess of dopamine activity in certain regions of the brain. We will examine this more closely in Chapter 13.

Serotonin

Serotonin, distributed throughout the brain and spinal cord, is involved in the control of the sleep/wake cycle, mood, and appetite. Deficiencies in serotonin are associated with sleep disorders, aggression, eating disorders, and depression (Leu-Semenescu et al., 2010; Carrillo, Ricci, Coppersmith, & Melloni, Jr., 2009). The most widely prescribed antidepressants are a class of drugs called serotonin uptake inhibitors; Prozac® is an example of such an antidepressant. We discuss depression and its treatment in more detail in Chapter 13.

Gamma-Amino-Butyric Acid

Gamma-Amino-Butyric Acid (**GABA**) is the major inhibitory neurotransmitter in the brain and spinal cord. It plays an important role in regulating arousal and anxiety (Möhler, 2012). Drugs such as Valium® and Xanax® increase the activity of GABA, producing a calming effect and even sleep (Greiss & Fogari, 1980). Alcohol also increases GABA activity, contributing to its relaxing and sedative effects, as well as its disruptive effects on motor control and movement.

Endorphins

Endorphins are a family of neurotransmitters chemically similar to opiates such as morphine. They are widely distributed throughout most of the brain. Extensive research has linked endorphins to an array of behavioral and mental processes, including inducing a sense of well being and euphoria, counteracting the influence of stress, modulating food and liquid intake, facilitating learning and memory, and reducing pain. Medical science is particularly interested in the pain-reducing properties of endorphins, some of which may be as much as 100 times stronger than morphine. Researchers are hopeful that one day a synthetic version of these powerful brain chemicals will be developed for use in pain management (Janecka, Perlikowska, & Fichna, 2007).

Glutamate

Glutamate, or **glutamic acid**, is an amino acid derived from glucose. Glutamate is one of the most important excitatory neurotransmitters in the brain. It is believed to play an important role in a process called long-term potentiation, which is a change in neuronal functioning that mediates some forms of learning and memory (Robbins & Murphy, 2006). In fact, recent research suggests that learning and memory formation can be enhanced by drugs that facilitate glutamate activity (Kanno et al., 2012). The food additive monosodium glutamate (MSG) contains glutamate, and eating foods containing large amounts of MSG may produce symptoms of dizziness and numbness and actually impair learning and memory. This result is likely to be a consequence of overexciting glutamate

Norepinephrine A major excitatory neurotransmitter in the brain that is distributed throughout the central and peripheral nervous systems and is important in emotional arousal and stress

Dopamine A neurotransmitter involved with the initiation of motor movement, attention, and learning and memory (The dopamine system mediates reward and pleasure and is the substance of addiction.)

Serotonin A neurotransmitter involved in the control of the sleep/wake cycle, mood, and appetite (Deficiencies in serotonin are associated with sleep disorders, aggression, and depression.)

Gamma-Amino-Butyric Acid (GABA) A major inhibitory neurotransmitter in the brain and spinal cord that plays an important role in regulating arousal and anxiety

Endorphins A class of neurotransmitter substances that function to inhibit the transmission of pain information (Morphine and other opiates act by facilitating endorphin transmission.)

Glutamate (Glutamic Acid) An amino acid derived from glucose that plays an important excitatory function (MSG contains glutamate.)

neurons with excessive amounts of glutamate (Gonzalez-Burgos, Velázquez-Zamora, & Beas-Zárate, 2009).

The above discussion is only a brief review of several of the most important neurotransmitter substances. New neurotransmitters and other neuroactive chemicals are still being discovered and investigated. Such discoveries have been central to the development of the science of molecular neurobiology, a field devoted in part to a study of the molecular bases of behavior. At present, the number of substances identified and believed to be neurotransmitters exceeds fifty.

You may have noticed in Table 2-1 that different neurotransmitter substances seem to have different effects. Instead of transmission of a signal from one neuron to another, the function of some neurotransmitters is inhibitory (that is, instrumental in restraining or suppressing the transmission of neural impulses). This label may seem contrary to logic, especially since we have just seen that neurotransmitters are essential for the transmission of neural impulses. Sometimes, however, neurotransmitters have just the opposite effect.

(Shutterstock)

The food additive monosodium glutamate (MSG) contains glutamate. Eating foods containing large amounts of MSG, such as most fast food, may produce symptoms of dizziness and numbness.

As stated at the outset of the chapter, the nervous system is divided into two major divisions: the peripheral nervous system and the central nervous system. We will now examine these systems in some detail.

2.3 The Peripheral Nervous System

The peripheral nervous system (PNS) consists of all the nervous system structures located outside the central nervous system (CNS). Its primary purpose is to serve the CNS by transmitting information to and from the spinal cord and brain. Signals are carried to and from various structures to the spinal cord and the brain along bundles of myelinated axons called **nerves**. The PNS has two divisions: the somatic nervous system and the autonomic nervous system (see Figure 2-5).

Nerve A cable-like bundle of myelinated axons that transmits signals from various structures of the body to the spinal cord and the brain

2.3a The Somatic Nervous System

The **somatic nervous system** contains nerves that serve the major skeletal muscles, such as the arm and leg muscles. These muscles, often called striated because they appear striped when seen under a microscope, carry out intentional movements directed by messages from higher brain centers. The somatic nervous system also contains nerves that transmit sensory information from the skin, muscles, and various sensory organs of the body to the spinal cord and brain.

Somatic Nervous System Division of the peripheral nervous system that transmits messages to and from major skeletal muscles and from sensory organs to the central nervous system

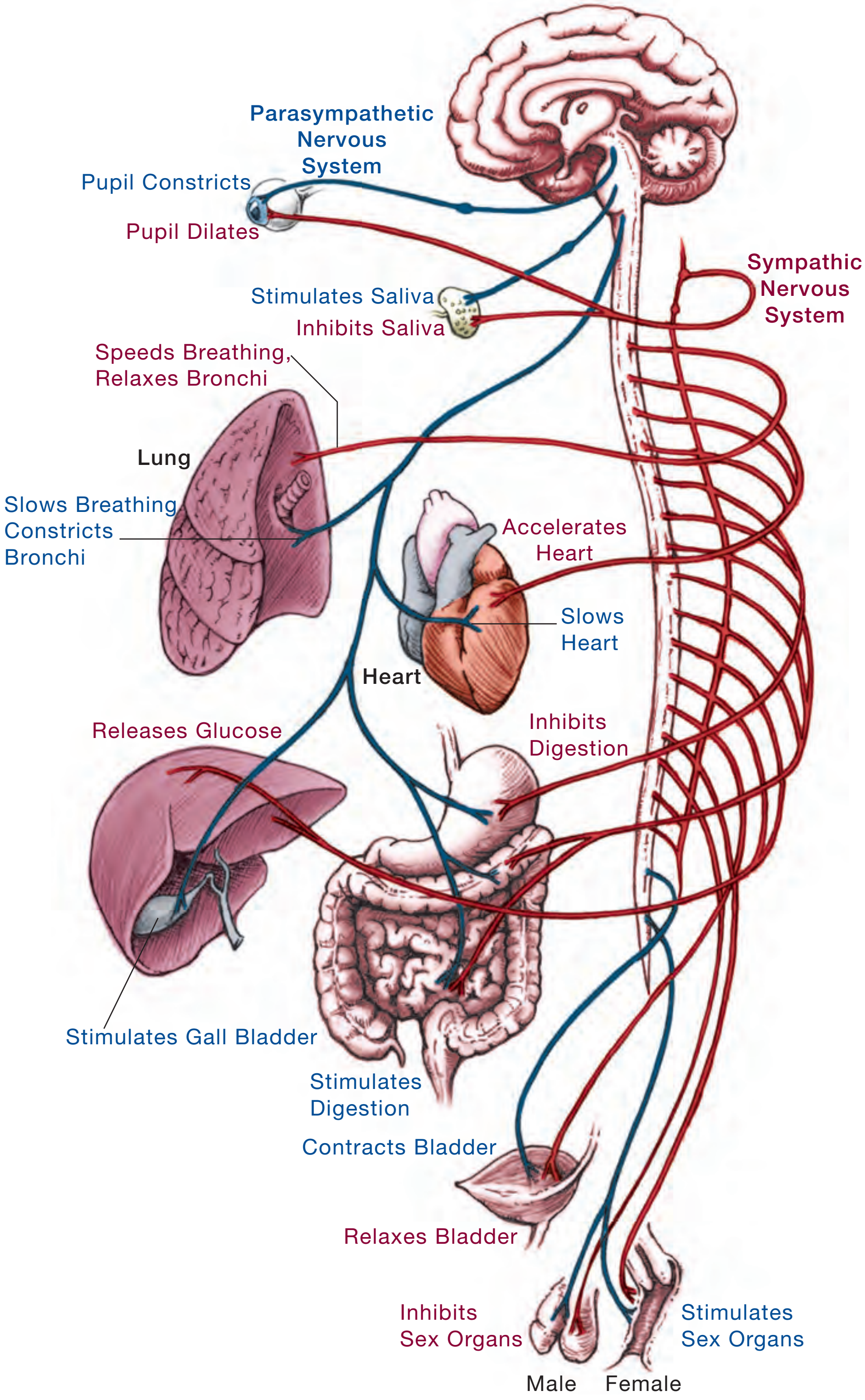
2.3b The Autonomic Nervous System

The other division of the PNS, the **autonomic nervous system** (**ANS**), controls the glands and the smooth muscles of the heart, lungs, stomach, intestines, blood vessels,

Autonomic Nervous System (ANS) Division of the peripheral nervous system that transmits messages between the central nervous system and the endocrine system, as well as the smooth muscles of the heart, lungs, stomach, and other internal organs that operate without intentional control

Figure 2-5 Functions of the Sympathetic and Parasympathetic Nervous Systems

These two systems work together to allow our bodies to react quickly to our environments and to relax.



and various other internal organs. The ANS is named for the fact that the muscles and glands it serves operate reflexively without intentional or voluntary control. Thus they are autonomous or self-regulating.

The autonomic nervous system is itself subdivided into two branches, the **sympathetic** and the **parasympathetic**. In most cases, each internal organ serviced by the autonomic nervous system has a separate set of connections with the sympathetic and the parasympathetic branches. These two distinct sets of connections operate quite differently, often having opposing effects on the organs they control, as shown in Figure 2-5. For example, the sympathetic system increases heart rate, dilates the pupils, and inhibits digestive activity; the parasympathetic system has the opposite effect in each case.

The sympathetic and parasympathetic systems do not operate in a counterproductive fashion, however. Instead, they work together to allow our bodies to function well when either relaxed or highly aroused. The balance between these two systems maintains our normal state, somewhere between extreme excitement and complete relaxation. However, there are times when we need an emergency source of energy, for example, when we are stressed or feeling strong emotion. At these times, our sympathetic nervous systems come into play.

For instance, imagine that you are hiking in the wilderness when a bear suddenly confronts you. The result will probably be the classic response that prepares you (and probably the bear, too) for fight or flight. Your pupils dilate, your heart pumps like mad, and epinephrine (commonly called adrenalin) pours into your blood vessels. These effects produce distinct sensations in your body, but they also serve a critical function. Under the influence of the sympathetic nervous system, organs such as the heart operate at their upper limits.

This response serves us well in emergencies, whether we need to escape from a bear in the woods or rescue a child from a burning house. However our bodies cannot continue at this pace for very long. If they did, we would soon be exhausted. It is at this point that the parasympathetic nervous system comes into play, providing a braking mechanism for each of the organs activated by the sympathetic nervous system. This counter system helps us conserve energy and resources, and it is active in restoring our bodies to normal.

Sympathetic and parasympathetic responses take place in different ways. The parasympathetic nervous system tends to affect specific glands and organs independently of one another, often one at a time. In an emergency, however, there is no time to waste. As a result, the sympathetic nervous system acts as a unit, simultaneously mobilizing most or all of the various sympathetic effects outlined in Figure 2-5.

2.4 The Central Nervous System: The Brain and Spinal Cord

The average human brain weighs approximately 1,390 grams (or roughly three pounds). It can store more information than many great libraries combined, and its communication network has more potential interconnections between cells than the number of atoms in our solar system. How does the brain work? How do electrical impulses and chemical transmissions translate to memories, creating insights, intelligence, and feelings? The answers to these questions are still far from complete, but we are piecing together more and more clues. Much of what we know has to do with the brain's physical structure.

If the top of a person's skull were removed so that you could look straight down on the brain, you would see something like the image in Figure 2-6. In its natural state, the human brain looks much like a soft, wrinkled walnut, its outer surface filled with crevices and folds. The left and right sides appear to be separated by a long, deep cleft (called the longitudinal sulcus) that runs from the front to the back. The area of the brain visible

Sympathetic Nervous System Division of the autonomic nervous system that functions to produce emergency responses, such as increased heart rate, pupil dilation, and inhibited digestive activity; works in tandem with the parasympathetic nervous system

Parasympathetic Nervous System Division of the autonomic nervous system that functions to conserve energy, returning the body to normal from emergency responses set in motion by the sympathetic nervous system

Cerebral Hemispheres The two sides (right and left) of the cerebrum

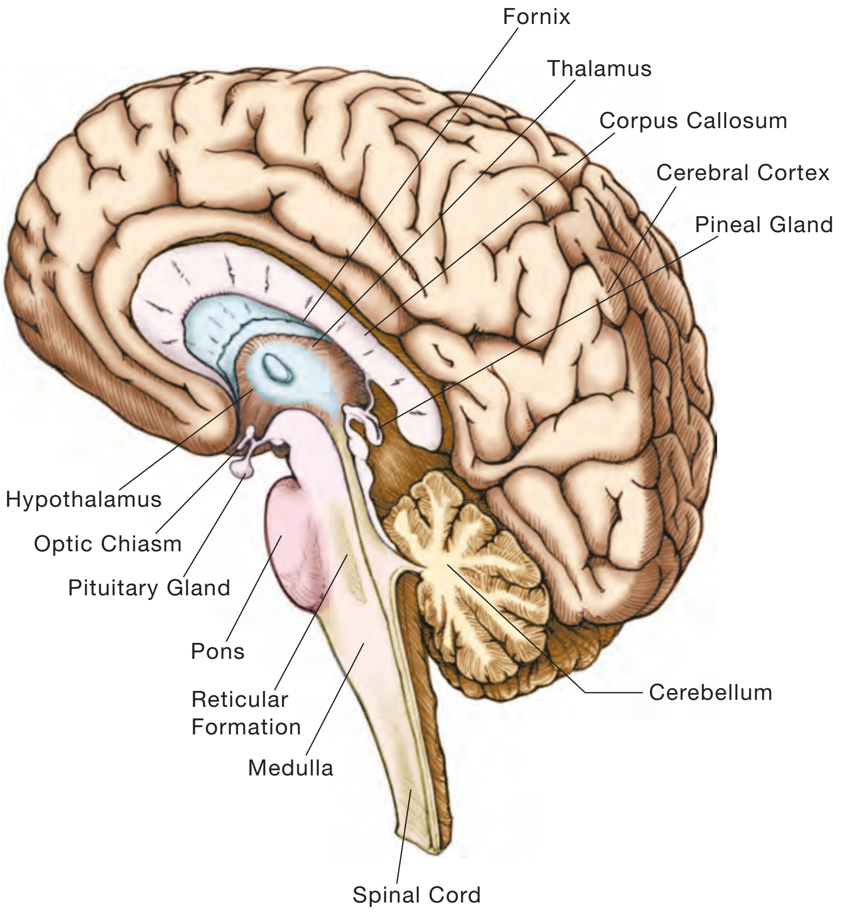
from the top is known as the cortex. The cortex is divided into two sides or **cerebral hemispheres** that, while not precisely identical, are almost mirror images of each other.

Under the cortex are many other structures, as shown in Figure 2-6. Starting from the spinal cord and working roughly upward through the base of the brain, these include the *medulla*, the *pons*, the *cerebellum*, the *reticular formation*, and the structures of the limbic system, the *hypothalamus*, and the *thalamus*.

2.4a The Spinal Cord

Housed within a hollow tubelike structure composed of a series of bones called vertebrae, the spinal cord looks something like a long, white, smooth rope extending from the neck to the small of the back. Along the length of the spinal cord are spinal nerves that branch out between pairs of vertebrae. These nerves connect with various sensory organs, muscles, and glands served by the peripheral nervous system. The spinal nerves occur in thirty-one matched pairs, with one nerve of each pair connected to the right side of the spinal cord and its counterpart connected to the left side. Thus, the spinal cord can help coordinate the two sides of the body.

Figure 2-6 Bisected View of the Human Brain Showing the Locations of Major Structures and Areas



Because the brain occupies the commanding position in the CNS, the spinal cord is often overlooked in discussions of the biological bases of behavior. However, the spinal cord fills the very important function of conveying messages to and from the brain. In addition, the spinal cord controls reflexes, which are simple circuits of sensory and motor neurons that initiate responses to specific stimuli.

All complex behaviors require integration and coordination at the level of the brain. However, certain basic reflexive behaviors (such as a leg jerk in response to a tap on the kneecap or the quick withdrawal of a hand from a hot stove) do not require brain processing. Different parts of the spinal cord control different reflexes. For example, hand withdrawal is controlled by the upper spinal cord, whereas an area in the lower cord controls the knee-jerk response. The brain is not directly involved in controlling these simple reflexive responses, but it is clearly aware of what action has transpired (see Figure 2-7).

Medulla Structure low in the brain that controls vital life support functions such as breathing, heartbeat, and blood pressure, as well as many reflexive functions such as coughing and sneezing

2.4b The Medulla

The **medulla** is the lowest part of the brain, located just above the spinal cord. This structure is in a well-protected location, deep and low within the brain. The placement is fortunate since the medulla contains centers that control many vital life-support functions such as breathing, heart rate, and blood pressure. Even the slightest damage in a critical region of the medulla can cause death. The medulla also plays an important role in regulating other reflexive, automatic physiological functions such as sneezing, coughing, and vomiting.

Figure 2-7 Simple Reflex

A simple reflexive response involves the interaction of a sensory neuron, an interneuron, and a motor neuron. Interneurons function to both convey sensory information to the brain and to stimulate motor neurons to activate the withdrawal reflex.

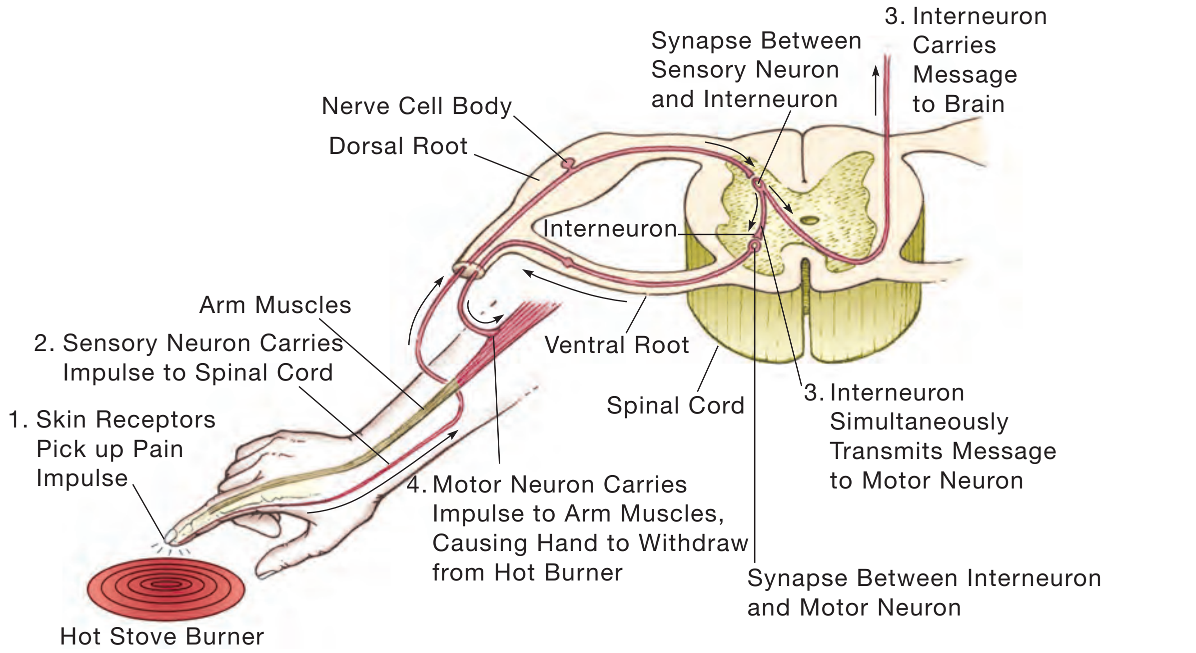
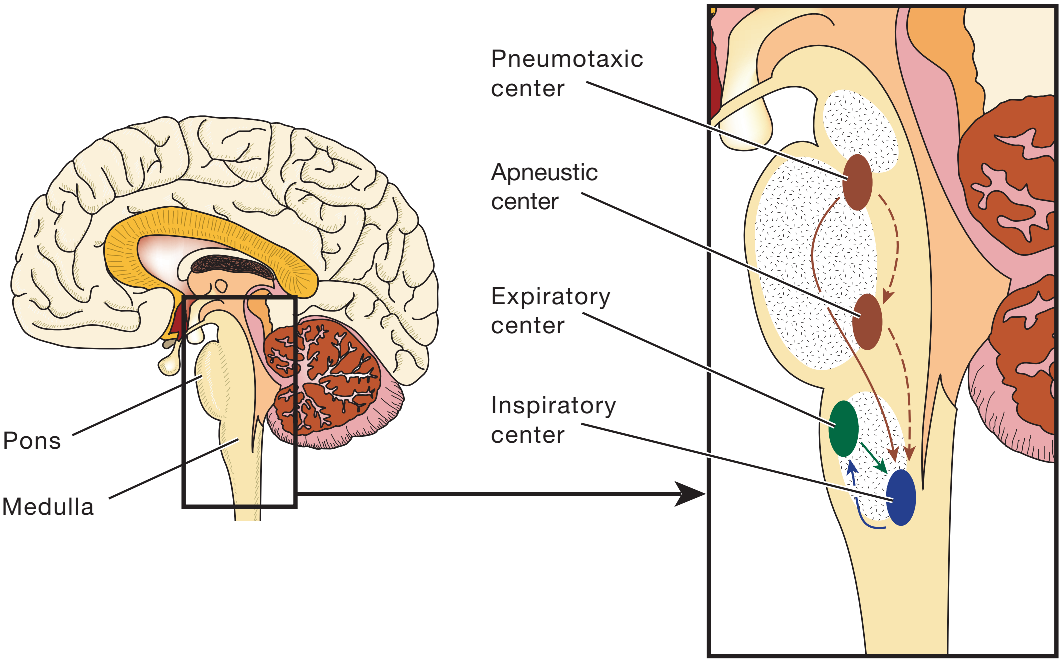


Figure 2-8 Medulla

The medulla controls several vital life functions, including control of heart rate and respiration.



2.4c The Pons

The **pons** is a large bulge in the lower brain core, just above the medulla. The pons plays an important role in fine-tuning motor messages as they travel from the motor area of the cerebral cortex down through the pons to the cerebellum. Species-typical behaviors (such as feeding patterns) are mediated by the pons, which appears to program the patterns of muscle movement that produce these behaviors.

The pons also plays a role in processing some sensory information, particularly visual information. In addition, the pons contains specialized nuclei that help control respiration, mediate pain and analgesia, and influence facial expression.

Pons Brain structure located just above the medulla that functions in fine-tuning motor messages, programming species-typical behaviors, processing sensory information, and controlling respiration

Cerebellum Brain structure located beneath the overhanging back part of the cerebral hemispheres that functions to coordinate and regulate motor movements

2.4d The Cerebellum

The **cerebellum** is a distinctive structure, about the size of a fist, tucked beneath the back part of the cerebral hemispheres. It consists of two wrinkled hemispheres covered by an outer cortex. The cerebellum's primary function is to coordinate and regulate motor movements that are broadly controlled by higher brain centers. The cerebellum fine-tunes and smooths out movements, particularly those required for rapid changes in direction. For example, when you reach out to catch a moving ball, your cerebellum is involved in the timing of your movements. This kind of timed movement clearly involves learning. Experiments with animals have shown that the activity of specific cells in the cerebellum changes during the course of learning and that blocking projections from cells within the cerebellum disrupts learned responses (Wikgren, Lavond, Ruusuvirta, & Korhonen, 2006).

Damage to the cerebellum results in awkward, jerky, uncoordinated movements and may even affect speech. Professional boxers are especially susceptible to slight damage to the cerebellum, which results in a condition called punch-drunk syndrome. Motor impairment following alcohol intoxication may also be related to cellular changes in the cerebellum. Researchers have demonstrated that alcohol facilitates inhibition in the cerebellum by activating GABA receptors.

2.4e The Reticular Formation

The **reticular formation** consists of a set of neural circuits that extend from the lower brain, where the spinal cord enters, up to the thalamus (refer back to Figure 2-6). Research has demonstrated that the reticular formation plays a critical role in consciousness and in controlling arousal or alertness. For this reason, it has become common to refer to this weblike collection of nerve cells and fibers as the **reticular activating system**, or **RAS**. These neurons are primarily noradrenergic; that is, they use the neurotransmitter norepinephrine. Stimulants such as amphetamine and Ritalin facilitate norepinephrine and increase alertness. Research suggests that attention deficit hyperactivity disorder (ADHD) results from insufficient, rather than excessive, arousal produced by the noradrenergic system, explaining why treatment with amphetamines is often successful (Pliszka, McCracken, & Maas, 1996; Halperin et al., 1997; Zikopoulos & Barbas, 2007; Hodgkins, Shaw, McCarthy, & Sallee, 2012).

Some of the neural circuits that carry sensory messages from the lower regions of the brain to the higher brain areas have ancillary or detouring fibers that connect with the reticular system. Impulses from these fibers prompt the reticular formation to send signals upward, making us more responsive and alert to our environment. Experiments have shown that mild electrical stimulation of certain areas within this network causes sleeping animals to awaken slowly, whereas stronger stimulation causes animals to awaken rapidly, with greater alertness.

The reticular formation also seems to be linked to sleep cycles. When we fall asleep, our reticular systems cease to send alerting messages to our brains. While sleeping, we may screen out our extraneous stimuli, with the possible exception of critical messages such as the sounds of thunder or a baby's cough. Although the role of the reticular formation in sleep is still not fully understood, we do know that reticular neurons inhibit sleep-active neurons during wakefulness (Osaka & Matsumura, 1994) and that serious damage to this structure may cause a person to be extremely lethargic or to enter into a prolonged coma. Recent evidence also suggests that patients in a severe coma may be aroused by electrical stimulation of the reticular system (J. Cooper, Jane, Alves, & E. Cooper, 1999; E. Cooper, Scherder, & J. Cooper, 2005). The role of the RAS on sleep and dreaming patterns is considered further in Chapter 4.

Reticular Formation Set of neural circuits extending from the lower brain up to the thalamus; plays a critical role in controlling arousal and alertness; also known as the *reticular activating system (RAS)*

Reticular Activating System (RAS) Set of neural circuits extending from the lower brain up to the thalamus; plays a critical role in controlling arousal and alertness

Limbic System Collection of structures located around the central core of the brain that play a critical role in emotional expression, as well as motivation, learning, and memory (Key structures of the limbic system include the amygdala, the septal area, and parts of the hypothalamus.

2.5 The Limbic System

The **limbic system** is the portion of the brain most closely associated with emotional expression; it also plays a role in motivation, learning, and memory. The limbic system is a collection of structures located around the central core of the brain, along the innermost edge of the cerebral hemispheres. Figure 2-9 shows some key structures of the

Amygdala A small limbic-system structure located next to the hippocampus in the brain that plays an important role in the expression of anger, rage, fear, and aggressive behavior

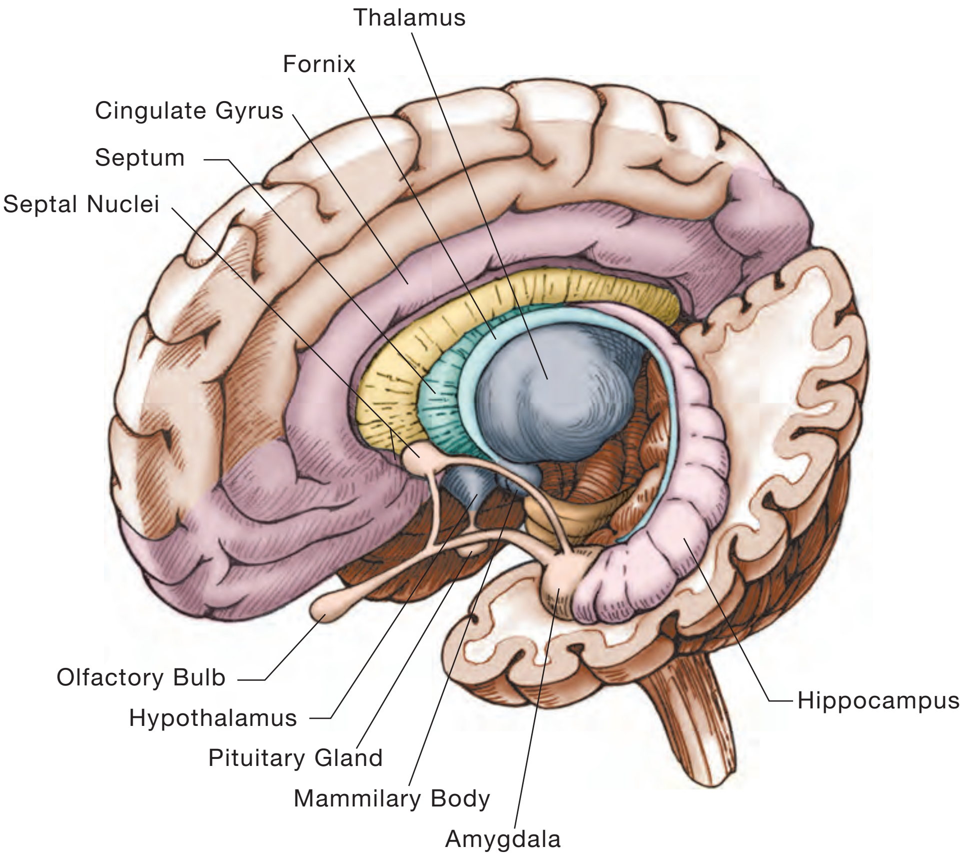
limbic system, including the amygdala, the hippocampus, the septal area, and parts of the hypothalamus. Damage to or stimulation of sites within this system may profoundly affect emotional expression, either by causing excessive reactions to situations or by greatly reducing emotional responses (Halpern & O'Connell, 2000).

2.5a The Amygdala

The **amygdala**, a small structure next to the hippocampus, plays an important role in the expression of anger, rage, and aggressive and fear-motivated behavior. Electrical stimulation or surgical damage to some areas of the amygdala may cause an animal to go into a blind rage, attacking everything in sight, whereas in other parts of the amygdala the same procedures may produce extreme passivity, even in threatening situations. Researchers also believe that the amygdala plays significant roles in social cognition and in decision making.

Figure 2-9 The Limbic System

Major limbic structures include the amygdala, the septum and septal nuclei, the fornix, the hypothalamus, and the cingulate gyrus.



Adapted figure of "Primary Areas of the Motor Cortex and Somatosensory Cortex," article from "Specializations of the Human Brain" from *Scientific American,* September 1982, p. 182, by Norman Geschwind.

Amygdala damage in humans results in the inability of thoughts or memories to trigger emotional states. These emotional states are essential to normal social functioning and decision making. For example, when you see a snake, or even think of snakes, an aversive emotional state is produced, motivating you to stay away. Likewise, when you make a decision to invest a large sum of money, an emotional state induced by the thought of either making more or losing it all guides your decision to invest, or not. People with amygdala damage lose these functions, making decisions difficult (Bechara & H. Damasio, 2002; Bechara, H. Damasio, & A. Damasio, 2003; Clark et al., 2008; Damasio, 1995).

2.5b The Hippocampus

Another limbic-system structure, the **hippocampus**, seems to be important for learning and memory. Individuals who experience damage to this structure have difficulty storing new information in memory. In one sad case, a man whose hippocampus was completely removed from both sides of his brain was unable to retain any new information in memory. He remembered skills and information learned prior to the surgery but was unable to store memories of anything that happened after the surgery. We discuss the implications of this finding in Chapter 6. Recent evidence suggests that the hippocampus may also undergo significant alterations as a result of stress during early development. For example, a study of women who had a history of childhood sexual abuse or posttraumatic stress disorder found that hippocampal size was decreased by 19 percent compared to control subjects who had no such history. Hippocampal function was also significantly reduced in these women (Bremmer et al., 2003; Nemeroff et al., 2006). Whether these deficits were significant enough to impair learning and memory is unknown.

2.5c The Septum

Still another area of the limbic system, the **septal area**, is associated with the experience of pleasure. James Olds demonstrated this in the 1950s in a series of experiments on brain stimulation in rats, which were mentioned in Chapter 1. Olds implanted electrodes in various regions of rats' limbic systems and wired the electrodes in a way that allowed the rats to stimulate their own brains by pressing a lever. When the electrodes were placed in sites within the hypothalamus and the septal area, the rats seemingly could not get enough stimulation. They would press the lever several thousand times per hour, often to the point of exhaustion. Because the animals labored so incessantly to produce this experience, such behavior was interpreted as meaning they liked the feeling. In fact, it seemed as though they were experiencing something akin to intense pleasure, which led to the label "pleasure center" (Olds, 1956).

Researchers have been more reluctant to study the effects of stimulating human limbic systems, although a similar procedure has been used in a few instances to achieve therapeutic effects. Robert Heath (1972), a Tulane University researcher, is one of the pioneers in this area. In the early 1970s, he experimented with limbic system stimulation on two subjects, a female epileptic and a man troubled with emotional problems. Heath hypothesized that the pleasure associated with such stimulation would be of therapeutic value to these patients. When stimulation was delivered to the septal area, both individuals reported intense pleasure. The male patient, in fact, used a self-stimulating transistorized device to stimulate himself incessantly (up to 1,500 times per hour). According to Heath, "He protested each time the unit was taken from him, pleading to self-stimulate just a few more times" (p. 6).

Hippocampus Structure in the brain's limbic system that seems to play an important role in memory

Septal Area Structure in the brain's limbic system that plays a role in experiencing pleasure

In other kinds of motivated behavior, such as eating, drinking, and sexual behavior, organisms typically cease when they are satiated; however, this did not happen in experiments like those just described. Why? This question and related questions have led to the development of a separate area of study called intracranial self-stimulation (Olds & Forbes, 1981). Researchers are actively involved in seeking to understand the mechanisms that underlie the reinforcing effects of electrical stimulation of various brain sites. Research suggests that the dopamine system plays an important role in the mediation of reinforcement associated with *intracranial self-stimulation* as well as with drugs such as cocaine. When laboratory animals are administered drugs that temporarily block dopamine receptors in the brain, self-stimulation behavior is suppressed. The brain areas believed to be involved in pleasure and reward are referred to as the **mesolimbic-cortical system**, which includes the septum, the nucleus accumbens, and pathways leading to the frontal cortex.

2.5d The Hypothalamus

As its name **hypothalamus** indicates (*hypo* means below in Greek), this grape-sized structure lies below the thalamus. Although it is small, the hypothalamus has an important impact on several bodily functions and behaviors and thus has been a major focus of many investigations (some of which are discussed in later chapters). The hypothalamus contains control mechanisms that detect changes in body systems and correct imbalances to restore *homeostasis*, the maintenance of a relatively constant internal environment. Shivering when we are cold and perspiring when we are hot are both homeostatic processes that act to restore normal body temperature, and both are controlled by the hypothalamus. The hypothalamus is also critical to motivation. It contains nuclei (densely packed concentrations of specialized cell bodies) that govern eating, drinking, and sexual behavior.

The hypothalamus is also the hub of the neuroendocrine system, which is discussed later in this chapter. This system—composed of the hypothalamus, pituitary gland, and various other hormone-secreting endocrine glands—is essential to a variety of behaviors, including sexual expression, reproduction, aggression, and reactions to stress. You may have heard the brain's pituitary gland described as the master gland since it secretes substances that control the activity of other glands throughout the body. However, the term *master* is somewhat a misnomer because the pituitary gland itself takes direction from the hypothalamus. The hypothalamus plays an integrative role in the expression of emotions, partly through interacting with the endocrine system and partly as a key member of the limbic system (Drevets, Price, & Furey, 2008).

Mesolimbic-Cortical System The system of dopamine-containing neurons that originate in the ventral pons, project through the nucleus accumbens and septum, and terminate in the frontal cortex; mediates the reinforcing effects of eating, sex, and addictive drugs

Hypothalamus Small structure located below the thalamus in the brain that plays an important role in motivation and emotional expression, as well as controlling the neuroendocrine system and maintaining the body's homeostasis; part of the limbic system

Thalamus Structure located beneath the cerebrum in the brain that functions as a relay station, routing incoming sensory information to appropriate areas in the cerebral cortex; also seems to play a role in regulating sleep cycles

2.5e The Thalamus

Located above the hypothalamus are two egg-shaped structures that lie side by side, one in each hemisphere. These are the left and right halves of the **thalamus**, a structure that has often been referred to as the brain's relay station because of the role it plays in routing incoming sensory information to appropriate areas within the cerebral cortex. Many of the cell nuclei in the thalamus also perform initial data processing before relaying information to the cortex.

Distinct regions in the thalamus are specialized for certain kinds of sensory information. For example, when you hear a sound, the message transmitted from your ears passes through specialized neurons in an auditory area of the thalamus and is then relayed to the auditory cortex, an area in the cerebral cortex specialized for processing sound impulses.

With the sole exception of the sense of smell, all sensory information is routed through specialized regions of the thalamus. In addition to this function, the thalamus also appears to work in conjunction with the reticular formation to help regulate attention and sleep cycles. ADHD appears to be caused by disruptions in brain circuits between the thalamus and the frontal cortex (Dickstein, Bannon, Castellanos, & Milham, 2006; Qiu et al., 2011).

2.6 The Basal Ganglia

The **basal ganglia** consist of several subcortical brain structures, including the **caudate nucleus**, the **putamen**, and the **substantia nigra**. These structures receive messages from the cortex and the thalamus. The primary function of the basal ganglia is in the control and initiation of motor movement. People with damage to the basal ganglia have great difficulty initiating movement. In addition, movement is often weak and poorly coordinated. One of the most common disorders of the basal ganglia is a condition referred to as Parkinson's disease, which results from the destruction of the dopamine-containing neurons of the substantia nigra. This disease occurs most often in the elderly; however, it may occur in individuals in their late forties or fifties, such as Michael J. Fox. Parkinson's disease is characterized by difficulty initiating movement, rigidity, and tremors, often in the hands. Parkinson's disease is commonly treated with drugs that increase dopamine neural transmission, but embryonic and stem cell transplants into the substantia nigra are perhaps the most promising treatments for the future (Correia, Anisimov, Li, & Brundin, 2006; Deierborg, Soulet, Roybon, Hall, & Brundin, 2008).

2.7 The Cerebral Cortex

A major structure of the human brain is the **cerebral cortex**, the thin outer layer of the brain. The Latin word *cortex* means bark, and the cortex covers the brain in much the same way as bark covers a tree trunk. This portion of the brain is also called the neocortex, or new cortex, since it was the last part of the brain to develop during evolution (see Figure 2-10).

You may wonder why the cortex is wrinkled and convoluted. The answer has to do with the economics of space. The cortex's folds and wrinkles are nature's solution to the problem of cramming the huge neocortical area into a relatively small space within the skull. In the same way that crumpling a piece of paper allows it to fit into a smaller container than will a flat sheet, the cortex's folds permit it to fit into the fixed space of the skull. The size of the skull is essentially fixed because increases in skull size would require commensurate increases in the size of female pelvic structures to allow for full-term childbirth. As this example illustrates, evolutionary changes to one structure often require changes to others.

The body is represented in an upside-down fashion along the motor cortex and the somatosensory cortex. Larger cortical areas represent the hands and face, due to the fact that these areas require more motor control and sensation.

The cortex is gray in color, which is why it is often referred to as the gray matter of the brain. The gray color comes from the lack of the whitish myelinated coating that insulates the neural fibers of the inner part of the brain. The inner core of the brain is often called the white matter because it contains three kinds of myelinated neural fibers: *commissural fibers*, which pass from one hemisphere to another; *projection fibers*, which convey impulses to and from the cortex; and *association fibers*, which connect various parts of the cortex

Basal Ganglia Neural structures involved in the initiation of motor movement and emotion that include the caudate nucleus, putamen, and the substantia nigra

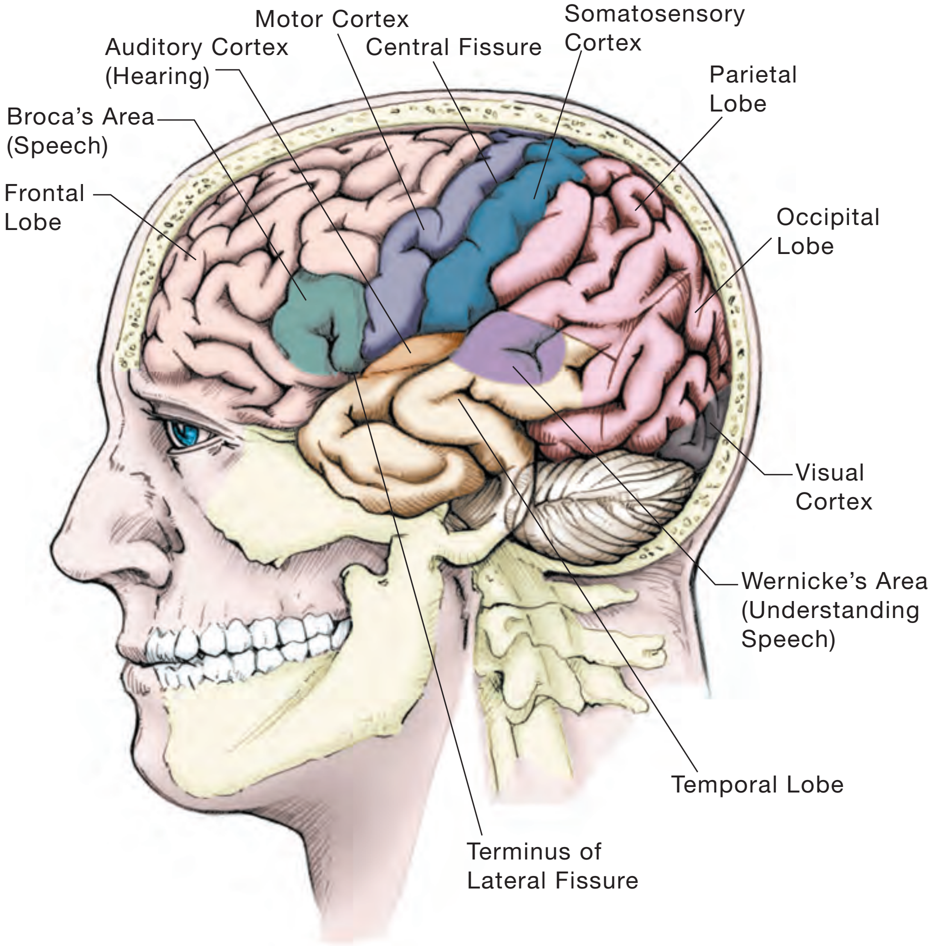
Caudate Nucleus A component of the basal ganglia involved with the control and initiation of motor movement; an area of the brain located adjacent to the putamen; affected by Huntington's disease

Putamen A component of the basal ganglia involved with the control and initiation of motor movement; an area of the brain located adjacent to the caudate nucleus; affected by Huntington's disease

Substantia Nigra A region of dark-colored neurons in the upper brain stem that sends axons to the caudate nucleus and to the putamen; an area of the brain affected by Parkinson's disease

Cerebral Cortex Thin outer layer of the brain's cerebrum that is responsible for movement, perception, thinking, and memory; sometimes called the *gray matter*

Figure 2-10 Localization of Cortical Functions in the Four Lobes of the Left Cerebral Cortex



within one hemisphere. The cortex is mainly composed of the unmyelinated fibers (thus its grayish brown appearance) and cell bodies of billions of neurons. It is the part of the brain responsible for higher processes such as perceiving, thinking, and remembering.

The cortex is the part of the brain in which our memories are stored, we make decisions, we see a sunset or recognize and appreciate a melody, and we organize our world and plan for the future. Without a cortex, we would cease to exist as unique, functioning individuals. This is not to say that the cortex acts alone in running our lives. Instead, it functions as an executive, interpreting incoming information and making decisions about how to respond. As we go about our daily lives, our cerebral cortex constantly analyzes a vast array of incoming messages, evaluating them against stored information about past experiences and then making decisions that are translated into messages and sent to other neural structures, appropriate muscles, and glands.

Although we know the cortex functions in this manner, we are far from understanding precisely how it controls our lives. For example, while we know that memory is largely a cortical function, science has yet to explain exactly how the brain initiates a command to search for and retrieve a specific recollection. Nor are we even sure where specific memories are stored, or how the cortex can spontaneously generate new ideas and insights. Investigations of the higher mental processes of the cortex are likely to remain at the frontier of psychology and neuroscience for many years to come, and only time will tell if science is capable of unraveling and understanding the most complex of its functions. Let us examine, however, what we do know about the functions of the cortex.

2.7a Localization of Cortical Functioning

As mentioned earlier, the two hemispheres of the brain are approximately symmetrical, with areas on the left side roughly matched by areas on the right. To some degree, researchers have been able to localize a variety of functions within various regions of the two cortical hemispheres. Approximately 25 percent of the total area of the cortex is involved in receiving sensory messages or transmitting movement messages to our muscles. These regions are called the **sensory cortex** and the **motor cortex**, respectively. The remaining 75 percent of the cerebral cortex, called the **association cortex**, is involved in integrating sensory and motor messages, and in processing such higher functions as thinking, language, perception, memory, and planning.

To facilitate studying and describing the brain, researchers have found it convenient to divide each of the cortical hemispheres into four separate regions called lobes. These four regions—the frontal, parietal, occipital, and temporal lobes—are shown in Figure 2-10. Two long fissures, called *sulci*, within the surface of the cortex separate these four lobes, and also serve as landmarks. The frontal lobe includes everything in front of the *center sulcus*, except the forward tip of the temporal lobe. The parietal lobe lies behind the central sulcus and above the *lateral sulcus*. The temporal lobe lies under the lateral sulcus, and the occipital lobe lies at the back of the brain.

The Frontal Lobe

The **frontal lobe** is the largest of the four lobes in each hemisphere and is an important center for both the motor and association cortex. The motor cortex, a narrow strip just in front of the central sulcus along the back of the frontal lobe, contains neurons that contribute to the control, planning, and execution of motor movement. Virtually all body movement, from throwing a ball to wiggling a small toe, involves the motor cortex.

The body is represented in an upside-down fashion along the motor cortex; that is, neurons controlling facial muscles are at the bottom of the motor cortex, and those that control movement of the toes are at the top part (see Figure 2-11.) Larger areas of the motor cortex are devoted to the muscles involved in talking and moving the fingers, reflecting the critical role of speech and tool use in human behavior.

Nerve fibers that descend from the motor cortex on one side of the brain activate muscles on the opposite side of the body. That is, the right motor cortex controls movements of the opposite, or contralateral, side of the body.

In the nineteenth century, a French neurosurgeon, Pierre Paul Broca, reported that damage to another area of the left frontal lobe caused difficulty in speaking. Subsequent research has confirmed that this frontal lobe region, called **Broca's area** after its discoverer, is the primary brain center for controlling speech (see Figure 2-10). People who have been injured in this critical area typically have trouble articulating the right words to describe things, even though their comprehension of what they hear or read is unaffected. This condition is called *expressive* or **Broca's aphasia**.

Sensory Cortex Region of the cerebral cortex that is involved in receiving sensory messages

Motor Cortex Region of the cerebral cortex that transmits messages to muscles and controls virtually all intentional body movements

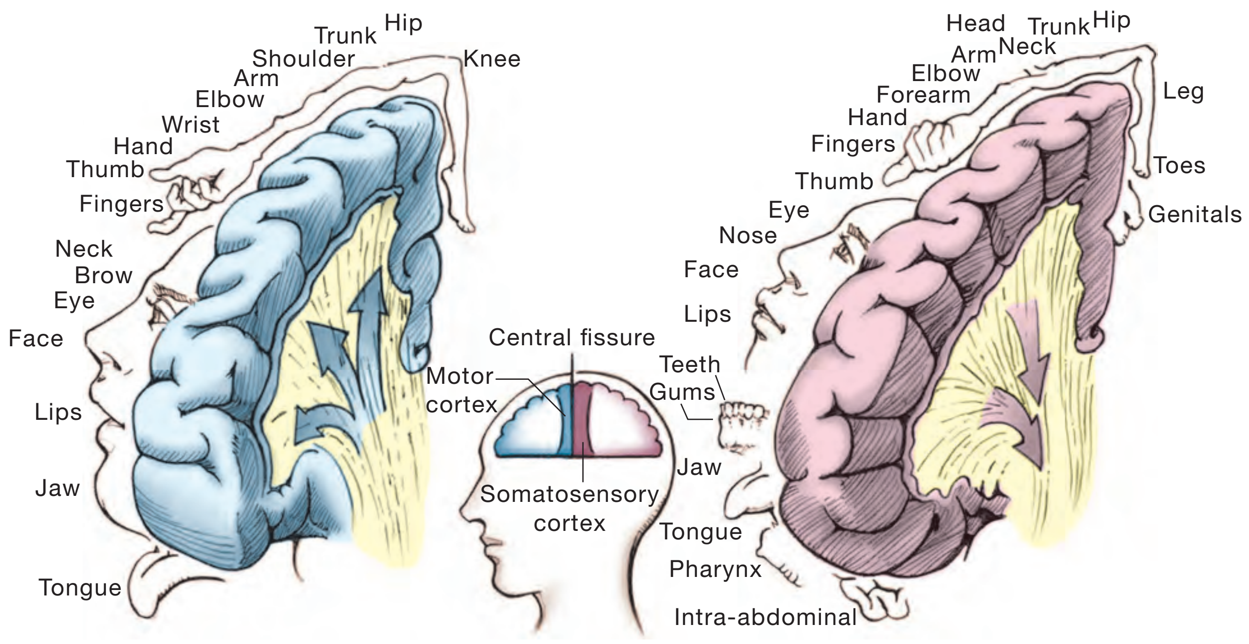
Association Cortex The largest portion of the cerebral cortex (about 75 percent); involved in integrating sensory and motor messages as well as processing higher functions such as thinking, interpreting, and remembering

Frontal Lobe Largest, foremost lobe in the cerebral cortex; an important region for movement, emotion, and memory

Broca's Area Region of the left frontal lobe that is the primary brain center for controlling speech

Broca's Aphasia The loss of the ability to speak or understand spoken or written language; also known as *expressive aphasia*

Figure 2-11 Primary Areas of the Motor Cortex and the Somatosensory Cortex



Motor Cortex
(cross-section just in front of central fissure)

Somatosensory Cortex
(cross-section just behind central fissure)

The association areas of the frontal lobes seem to be important in making decisions, solving problems, planning and setting goals, memory, and adapting to new situations. If the association areas were damaged, we would probably have trouble understanding complex ideas and planning and carrying out purposeful behavior. A considerable amount of our emotional lives is influenced by our frontal lobes as well. Extensive, reciprocal connections exist between the inferior (lower) frontal lobes and limbic system structures known to be involved in emotional behavior.

Well into the 1960s, a fairly common surgical procedure was used to separate the most forward part (prefrontal) of the frontal lobe from the rest of the cortex. This procedure, known as a prefrontal lobotomy, was carried out on thousands of patients as a desperate attempt to minimize their dysfunction and calm their moods. This procedure, wrought with severe criticism, met with limited success (Valenstein, 1973).

Parietal Lobe Region of the cerebral cortex located just behind the central fissure and above the lateral fissure; contains the somatosensory cortex as well as association areas that process sensory information received by the somatosensory cortex

Somatosensory Cortex Area of the parietal lobe, directly across from the motor cortex in the frontal lobe, that receives sensory information about touch, pressure, pain, temperature, and body position

The Parietal Lobe

The **parietal lobe** lies just behind the central fissure and above the lateral fissure. At the front of the parietal lobe, directly across from the motor cortex in the frontal lobe, is an area called the **somatosensory cortex**. This portion of the parietal lobe receives sensory information about touch, pressure, pain, temperature, and body position. Like the motor cortex, the somatosensory areas in each hemisphere receive sensory input from the opposite side of the body. Thus, when you stub your left toe, the message is sent to your right somatosensory cortex. As in the motor cortex, the body is represented in an upside-down fashion, with the largest portions receiving input from the face and hands, as shown in Figure 2-11. Each of the primary somatosensory areas in the parietal lobes lies directly across the central fissure from the corresponding area in the frontal lobe's motor cortex.

The parietal lobe is involved in relating visual and spatial information. For example, it allows you to know that an object is still the same even though you view it from a different angle and to identify objects by touch. The parietal lobe is also involved in complex visuospatial tasks such as mental rotation, which is the imaginary rotation of a familiar object in your mind. Researchers have demonstrated that mental rotation can be disrupted by magnetic interference of neural activity in the right parietal lobe (Harris & Miniussi, 2003). People with damage to their parietal lobe also suffer a peculiar deficit referred to as sensory neglect. Sensory neglect occurs to the contralateral side of the body (opposite from the side of the brain that was damaged). That is, a person with damage to the left parietal lobe may neglect the right side of the body by failing to dress it as neatly as the left side or may draw a self-portrait with the right side either missing or drawn with a marked lack of detail. While reading, a person with sensory neglect may read only the left side of a page. Such people also have difficulty following directions, either from instructions or from a map.

The Occipital Lobe

At the rear of each hemisphere lies the **occipital lobe**. This lobe consists primarily of the **visual cortex**, a complex network of neurons devoted to vision. Most people think they see with their eyes; but although the eyes receive sensory information, it is the visual cortex that integrates this information into vision. The visual cortex of each hemisphere receives sensory messages from both eyes. Nerve fibers from the right visual field of each eye go to the right hemisphere; fibers from the left visual field send impulses to the left hemisphere. In addition to receiving primary visual information, the visual cortex is also responsible for the processing of color, shape, three-dimensional form, and motion of objects. As you can imagine, damage to the occipital lobe results in varying degrees of visual impairment, ranging from the inability to perceive shapes, colors and motion, to complete blindness.

The Temporal Lobe

A primary function of the **temporal lobe** is hearing. The **auditory cortex**, located on the inner surface of the temporal lobe in a region below the lateral sulcus, receives information directly from the auditory system. These auditory signals are then transmitted to an adjacent structure, known as **Wernicke's area**, which is involved in interpreting sounds, particularly the sound of human speech (refer back to Figure 2-9). This area was named after Germany's Carl Wernicke, who reported that patients who were injured in the rear portion of the left temporal lobe, just below the lateral sulcus, often had trouble understanding the speech of others. This condition is known as **Wernicke's aphasia**. Another major function of the temporal lobe is object recognition and identification. Damage to either temporal lobe can cause peculiar disorders referred to as **agnosias**, where patients cannot name or identify familiar objects. One of the most thoroughly studied agnosias is called **prosopagnosia**, which is the inability to recognize familiar faces, even though the person could be recognized by other nonfacial cues such as voice.

Occipital Lobe Region at the rear of the cerebral cortex that consists primarily of the visual cortex

Visual Cortex Portion of the occipital lobe that integrates sensory information received from the eyes into electrical patterns that the brain translates into vision

Temporal Lobe Region of the cerebral cortex located below the lateral fissure that contains the auditory cortex

Auditory Cortex Region of the temporal lobe located just below the lateral fissure that is involved in responding to auditory signals, particularly the sound of human speech

Wernicke's Area Area of the left temporal lobe that is the brain's primary area for understanding speech

Wernicke's Aphasia A loss of the ability to comprehend spoken or written language; also referred to as *receptive aphasia*

Agnosia An inability to know or recognize objects through the senses; usually caused by brain injury or disease resulting in the failure to recognize or identify objects visually even though they can be seen

Prosopagnosia An inability to visually recognize particular faces; usually caused by brain disease or injury (Patients with prosopagnosia can see a face but may not be able to recognize it as familiar.)

2.7b Lateralization of Function

You may have noticed in a preceding discussion that both Broca's area and Wernicke's area were identified in the left hemisphere. Indeed, in most people (approximately 96 percent of right-handed people and 70 percent of left-handers), verbal abilities such as the expression and understanding of speech are governed more by the left hemisphere than the right hemisphere, and there are other differences as well. Furthermore, the right side of the brain seems to be more specialized for spatial orientation, including the ability to recognize objects and shapes and to perceive relationships among them.

The term **lateralization of function** is used to describe the degree to which a particular function is controlled by one hemisphere rather than both. If, for example, a person's ability to deal with spatial tasks is controlled exclusively by the right hemisphere, we would say that such an ability in this person is highly lateralized. In contrast, if both hemispheres contribute equally to this function, the person would be considered bilateral for spatial ability.

Studies have shown that the two hemispheres are asymmetrical, differing in anatomical, electrical, and chemical properties. Although each hemisphere is specialized to handle different functions, they are not entirely separate systems. Rather, our brains function mostly as an integrated whole. The two hemispheres constantly communicate with each other through a broad band of millions of connecting nerve fibers called the **corpus callosum**, shown earlier in Figure 2-6. While in most people a complex function such as language is controlled primarily by regions in the left hemisphere, interaction and communication with the right hemisphere also play a role. Furthermore, if a hemisphere that is primarily responsible for a particular function is damaged, the remaining intact hemisphere may take over the function. For example, if a person were to experience an injury to the language-processing area of the left hemisphere, the right hemisphere might develop a greater capacity to handle verbal functions. This is particularly true if the damage occurs early in life.

A vivid example of this phenomenon was provided in a report of an adolescent female who underwent surgical removal of her left hemisphere due to severe, progressive brain disease. Prior to the onset of her illness she was a normal, right-handed girl with above average language and reading capabilities. After surgery, her verbal skills were markedly diminished, a finding consistent with loss of the hemisphere that had governed most of her verbal skills prior to the hemispherectomy. However, her right hemisphere clearly was able to assume the direction and organization of at least some verbal abilities, as evidenced by her demonstrated ability to recognize and comprehend words and to engage in oral reading of familiar material (Patterson, Vargha-Khadem, & Polkey, 1989). This capacity to switch cortical control from one hemisphere to another tends to diminish as we grow older.

Split-Brain Research

Many important discoveries about how each hemisphere influences behavior have come from split-brain research, which began in the 1950s with Roger Sperry's investigations of cats whose brains had been bisected. Initially, Sperry and his colleagues made the startling discovery that the left hemisphere of a split-brain cat could learn something while the right hemisphere remained ignorant of what had been learned, and vice versa (Sperry, 1968). In the decades since this landmark study, additional experiments with split-brain subjects have added greatly to our knowledge about hemispheric lateralization of function.

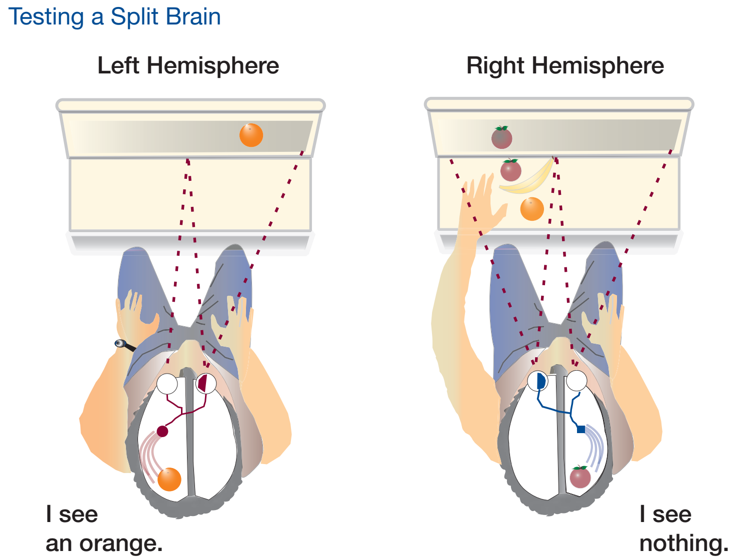
Some of these studies have involved split-brain research with human subjects. This radical surgery is not performed for experimental purposes but is occasionally performed

Lateralization of Function Degree to which a particular function, such as the understanding of speech, is controlled by one rather than both cerebral hemispheres

Corpus Callosum Broad band of nerve fibers that connects the left and right hemispheres of the cerebral cortex

Figure 2-12 Split-Brain Research

When the image of the orange enters the right visual field it crosses to the left hemisphere where the subject can articulate what he saw. When the image enters the right hemisphere the participant reports that he saw nothing.



to control very severe cases of epilepsy that have become incapacitating and even life threatening. During an epileptic seizure, neurons in the site of a damaged area begin to fire, and the abnormal activity can spread from one hemisphere to the other through the corpus callosum. Although drugs are often successful in decreasing the abnormal brain activity, the medication is not always effective; in these cases the only recourse may be to sever the corpus callosum. This procedure is usually very effective in controlling the seizure; the patients appear to be essentially unchanged in intelligence, personality characteristics, and behavior. However, their brains do not function in entirely the same manner after the surgery. After being disconnected, the two hemispheres operate independently: Their motor mechanisms, sensory systems, and association areas can no longer exchange information.

This difference makes itself felt in a variety of ways. For instance, the right hand might arrange some flowers in a vase, only to have the left hand tear it apart. Occasionally, people with split brains may be embarrassed by the left hand making inappropriate gestures, or perhaps doing some bizarre thing like zipping down the fly on a pair of trousers after the right hand zipped it up. With time, such symptoms usually subside as the person learns to compensate for and adjust to the independent functioning of the two hemispheres.

Scientists have developed a number of procedures for detecting the effects of split-brain surgery. For instance, in one study a woman recently recovered from split-brain surgery sat in front of a screen while pictures were flashed to either the left or the right of her visual field. Information presented to her left visual field was transmitted only to her right hemisphere, and vice versa. Each stimulus appeared on the screen for only about one-tenth of a second, so that the subject did not have time to shift her eyes to get a better look. Her task was to identify verbally what she was shown and then to reach under

BVT Lab

Flashcards are available for this chapter at www.BVTLab.com.

the screen and select the object, solely by touch, from a collection of objects (LeDoux, Wilson, & Gazzaniga, 1977).

Images in the right visual field fall on the left side of each retina (the image-recording part of the eye), and images in the left visual field fall on the right side on each retina. Half of each retina sends information to the occipital cortex on the same side of the brain, while information from the other half of each retina crosses over to the cortex on the opposite side of the brain. Thus, if a person stares straight ahead, information from the entire left visual field will reach the right hemisphere and vice versa.

Normally, this information is transferred between the two hemispheres through the corpus callosum, so that both hemispheres have information about both the left and right visual fields. In split-brain people, however, this is no longer possible (see Figure 2-13). In this particular experiment, researchers made sure that both fields did not receive the information by flashing the image for such a short period of time that each hemisphere received only the information in the opposite visual field. (In one-tenth of a second, the subject would not have time to shift her eyes, an action that would have enabled her to perceive the image in both hemispheres.)

Testing the Effects of Split-Brain Surgery

In the experiment just described, do you think that the woman was able to identify correctly, both verbally and by touch, objects projected in the left and right visual fields? If yes, why? If no, why not? What differences, if any, do you think were noted between her responses to left versus right visual field images? Take some time to reason out the probable results of this experiment.

The results of the experiment showed a difference in the subject's responses to images presented in her left and right visual fields. When a picture of a cup was projected to the right of the dot (and thus projected to her left hemisphere), the subject was able to quickly name the object, and she had no trouble locating the cup by touch. (She could locate the object with her left hand since naming the object out loud conveyed information about its nature to her right hemisphere via auditory input from her ears.) Additional objects presented to her right visual field presented no problems.

When a picture of a spoon was flashed to the left side of the dot, however, the results were quite different. The subject reported seeing nothing. Despite this reply, the researchers pressed her into trying to pick out the object from the articles on the table. After feeling the various objects with her left hand, she held up the spoon, a result she dismissed as a lucky guess. When asked to identify it verbally, she called it a pencil. Time after time, her sense of touch allowed her to identify objects presented to her right hemisphere, even though she insisted that she saw nothing each time a new image was flashed.

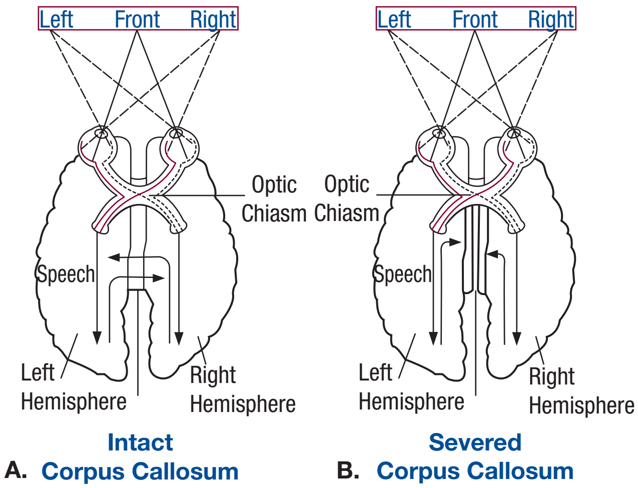
In a variation of this test, a sexually suggestive picture of a nude was flashed to the left side of the dot. The subject giggled and blushed, but when she was asked what she saw, she replied, "Nothing, just a flash of light." When the experimenter pressed further and asked why she was laughing, she exclaimed, "Oh, Doctor, you have some machine!"

These results reveal that in this individual (as well as in the majority of people) the left hemisphere is primarily responsible for language and speech. People with intact brains have no problem with tasks such as the one just described since the two hemispheres work together in perceiving and naming things. However, after a split-brain operation, each side of the bisected brain is cut off from the other side. Therefore, even though the subject of this study was able to identify the spoon with her hand, she could not name it. Her right hemisphere, with its undeveloped language and speech areas, was essentially mute. Her response to the picture of the nude was similar. Even though her left

Figure 2-13 Passage of Visual Information in Brains with an Intact and a Severed Corpus Callosum

A. When the corpus callosum is intact, visual information in the right visual field is focused on the left half of each retina; it then passes through the optic nerve to the left hemisphere of the brain. Information from either hemisphere can pass through the corpus callosum to the opposite side.

B. When the corpus callosum is severed, information from the eyes is transmitted to the brain in the same way as described above. However, information from the left visual field (in the right hemisphere) cannot be processed by the left hemisphere (where language areas are located).



hemisphere did not know what had happened, her blushing and giggling revealed that her right hemisphere had processed the information and produced an emotional response.

Would she have been able to identify the spoon with her right hand after its image had been projected to the right side of her brain? The answer is no. Since the left hemisphere governs her right hand, and her left hemisphere knew nothing about the object, she would have been unable to identify it with her right hand.

Investigating patients who have undergone split-brain surgery has also led to a better understanding of how the left and right hemispheres differ in respect to specific tasks. For example, the right hemisphere appears to specialize in our ability to recognize objects and familiar others. In an experiment with a split-brain patient, images of the self and other familiar people were presented to the left and right hemispheres independently, using a special projection device as described above. The patient easily recognized images of self when presented to either hemisphere but could only recognize familiar others when their images were presented to the right hemisphere (Uddin, Rayman, & Zaidel, 2005; Uddin et al., 2008).

The information presented in this chapter has only touched on what scientists know about the brain. Although there are still many unanswered questions, new methods developed in recent years have added greatly to our knowledge. In the next section, we look at some techniques used to study the brain.

2.7c How the Brain Is Studied

Surgical Lesions

As investigators attempted to link specific behavioral deficits with specific locations of brain damage, some of the earliest clues about how the brain functions came from observations of people with head injuries. For example, if a blow to the back of the head impaired a person's vision, the natural conclusion was that the injured region of the brain was responsible for vision. This way of learning about the brain has provided some valuable insights, but it also has some serious limitations. One is the impracticality of waiting for the right kind of injury to occur so that the role of a specific brain site can be assessed. In addition, it is often difficult to determine the precise location and amount of damage inflicted by a given injury. Because of such limitations, researchers concluded that it might be more efficient to create the injuries with surgical techniques. The areas of brain damage created by such procedures are called lesions, and the technique is called **lesion production**.

For obvious ethical reasons, lesion production is used with nonhuman subjects (although in some cases, lesions have been produced in human brains for therapeutic purposes, for example, to destroy an area in the amygdala that is responsible for abnormal cellular activity associated with uncontrollable rage). Typically, an animal is anesthetized, a small hole is drilled in its skull, and a specific part of the brain is destroyed. A special device called a *stereotaxic apparatus* allows researchers to insert a fine wire into a specific brain area. Sufficient electrical current is then passed through the wire to destroy a small amount of brain tissue at its tip. This refined lesion technique has allowed researchers to identify the relationship of specific behaviors to precise locations in the brain.

Brain Stimulation

A second technique, **brain stimulation**, involves stimulating precise regions with a weak electric current or specific chemicals that activate neurons. During electrical stimulation, a stereotaxic device is used to implant tiny wires called microelectrodes at specific brain sites. Stimulation of the targeted area often results in some kind of behavioral response (for instance, the pleasure response that results from stimulating the septal area).

During chemical stimulation a small syringe needle called a *microcanula* is inserted into a specific region of the brain. Once the microcanula is inserted, small amounts of chemical can be injected into surrounding cells, either stimulating or inhibiting specific receptors. Such results provide researchers with valuable information about where certain behavioral functions are localized within the brain. Because brain stimulation is generally painless, and because measures can be taken to minimize tissue damage, this method may be used with human as well as nonhuman subjects. For example, chemical stimulation of dopamine neurons in the nucleus accumbens with drugs like cocaine may help us understand the process of addiction.

Electrical Recording

Another technique used for studying the brain is **electrical recording**. In this technique, tiny wires implanted in the brain are used to record the electrical activity of neurons. Scientists using this technique have been able to record the responses of a single brain neuron to a stimulus such as a beam of light. In some studies, electrical activity is transmitted through several implanted electrodes while the subject engages in various

Lesion Production Technique for studying the brain that involves surgical damage to a precise region of the brain; most commonly done with experimental animals

Brain Stimulation Technique for studying the brain that involves stimulating precise regions with a weak electric current

Electrical Recording Technique for studying the brain in which tiny wires implanted in the brain are used to record neural electrical activity behaviors. The electrical messages are then fed into a computer, which analyzes the complex relationships between the behaviors and patterns of neuron activity.

Radioactive Labeling

At any given time, some areas of the brain are more active than others. While you are reading this text, your occipital lobes are more active than your frontal lobes. Likewise, when you smell perfume, your olfactory bulbs become more active. When cells—in this case neurons—become more active, they require more energy in the form of glucose, which is carried to cells via the blood supply. Researchers can take advantage of this fact and administer small amounts of radioactive chemical into the blood supply. One such chemical, called 2-deoxy-D-glucose (abbreviated as 2-DG), is taken into active cells just like glucose. Several hours later, the brain can be sliced into thin sections and placed on photographic plates. The sections of the brain that were most active following the administration of 2-DG are enhanced on the film. This technique, which is obviously restricted to laboratory animals, has been very valuable in identifying areas of the brain that are involved in different sensory, motor, and cognitive tasks.

Electroencephalography (EEG)

Lesion production, stimulation, electrical recording, and 2-DG studies are all *invasive* in that they require surgery. Fortunately, technology has made possible a variety of brain study methods that do not require surgery and are noninvasive. One technique, **electroencephalography** (**EEG**), has been around for quite some time. Because the brain constantly generates electrical activity, electrodes placed on the scalp can be used to record the electrical activity of the cortex. The electroencephalograph amplifies these very small electrical potentials thousands of times and records them on paper in patterns called brain waves. Brain waves vary according to a person's state—whether they are alert and mentally active, relaxed and calm, sleeping, or dreaming. The EEG has also been used to diagnose such conditions as epilepsy, attention disorders, brain tumors, and a variety of other neurological conditions that generate abnormal brain-wave patterns.

The EEG is also used to investigate attention processes by examining brain-wave patterns produced during stimulus presentation. These wave patterns associated with specific stimuli are called *evoked potentials*. Some years ago, research psychologists (Donchin & Herning, 1975) reported an interesting application of evoked potentials. Donchin recorded EEG activity in his subjects as they were exposed to various familiar or expected stimuli and an occasional unexpected or rare event. Enhanced computer analysis of the resulting evoked potentials revealed that the perception of an unexpected event was consistently associated with a particular brain-wave component called P300. For example, a subject might be exposed to a series of visual stimuli, some familiar and others not. In this case, the unfamiliar stimuli are unexpected and result in the recording of a P300 wave or evoked potential (P300 because it is a positive wave occurring 300 milliseconds after the unexpected stimulus). This kind of research contributes to our understanding of the relationship between mental processes, such as attention, and brain activity.

Electroencephalography (EEG) Technique used to measure and record electrical activity of the cortex

Computerized Axial Tomography (CAT) A procedure used to locate brain abnormalities that involves rotating an X-ray scanner around the skull to produce an accurate image of a living brain

Computerized Axial Tomography (CAT)

Neuroscientists have recently developed some effective techniques for observing living brains. The first of these, **computerized axial tomography** (**CAT**), was developed in the early 1970s. It is a refined X-ray technique that provides an accurate image of the brain. An X-ray scanner is rotated in a circular path around the skull, sending a thin beam of X-rays through the brain. A detector measures the amount of radiation that reaches the other side. Because different brain tissues absorb different amounts of radiation, the CAT scanners produce excellent pictures that can be used to locate tumors, lesions, and a variety of neurological abnormalities. In the past, this information could only be obtained by autopsy.

Positron Emission Tomography (PET)

A third noninvasive technique, the **PET** scan (**positron emission tomography**), also takes advantage of the fact that glucose is utilized at higher rates in active cells. Each time a neuron fires, it expends tremendous energy; thus, active brain cells metabolize a great deal of glucose. The scientists who developed the PET scan reasoned that if they could find a way to measure glucose utilization, they could tell which parts of the brain are active at different times in response to different stimuli. The use of radioactive isotopes paved the way.

The technique works as follows. A patient receives an intravenous injection of a glucose-like sugar that has been tagged with a radioactive fluoride isotope. Active brain cells then metabolize the sugar, but they cannot metabolize the radioactive component. Thus, the isotope accumulates within the cells in direct proportion to their activity level. As it decays, it emits charged particles called positrons. Instruments scanning the brain detect the radioactivity and record its location, and a computer converts this information into colored biochemical maps of the brain.

The PET scan has proven to be a useful tool in mapping the brain, pinpointing locations involved in movement, sensation, thinking, and even memory. There is also some evidence suggesting that PET scans may be helpful in both the diagnosis and treatment of various behavioral disorders. Some researchers report that the brains of schizophrenics and severely depressed people reveal different patterns from those of healthy people (Dunn et al., 2005).

Magnetic Resonance Imaging (MRI)

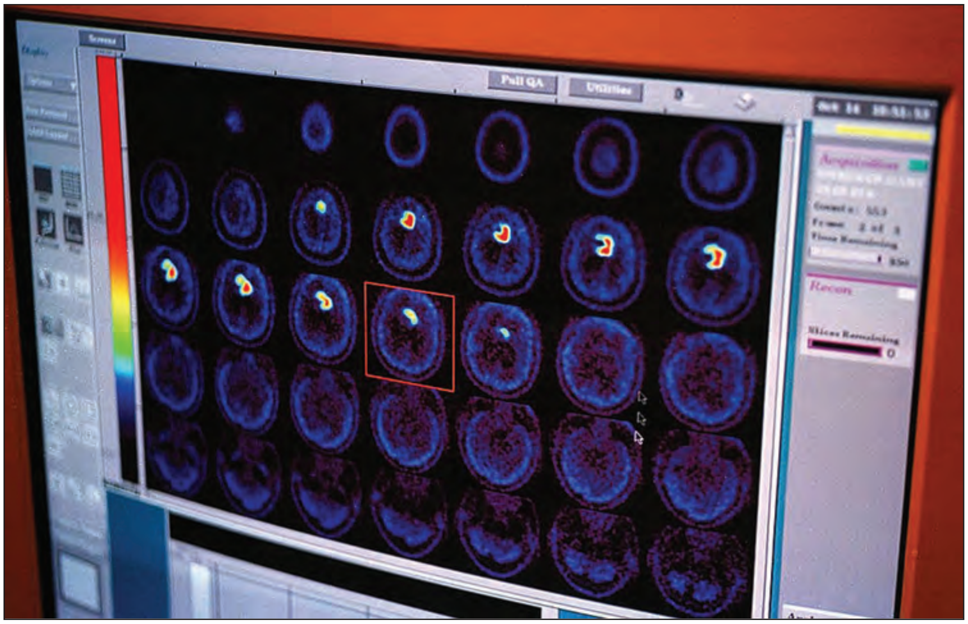
A fourth noninvasive technique is **magnetic resonance imaging** (**MRI**). This procedure uses harmless radio waves to excite hydrogen protons in the brain tissue, creating a magnetic field change that is detected by a huge magnet that surrounds the patient. The information is fed into a computer, which compiles it into a highly detailed, three-dimensional colored picture of the brain. The images created are much sharper and more detailed than those provided by the CAT scan. The MRI can pinpoint tumors and locate even the slightest reduction in blood flow in an artery or vein. It can also provide biochemical information, distinguishing between cancerous and noncancerous cells. In addition, MRI has been shown to be particularly helpful in diagnosing various diseases associated with brain abnormalities, such as multiple sclerosis, spinal cord abnormalities in children, and brain lesions associated with epilepsy.

A version of magnetic resonance imaging called **functional magnetic resonance imaging** (**fMRI**) provides high-resolution three-dimensional images of the brain during specific tasks. Regional changes in cerebral blood flow can be measured during a visual task, for example, and mapped onto an image of the brain's visual cortex. Researchers using fMRI can actually watch the brain as a subject is engaged in specific cognitive or motor tasks to determine the relative contributions of various brain areas to these activities.

Positron Emission Tomography (PET) Technique for studying the brain that involves injecting a subject with a glucose-like sugar tagged with a radioactive isotope that accumulates in brain cells in direct proportion to the activity level of those cells

Magnetic Resonance Imaging (MRI) Procedure for studying the brain that uses radio waves to excite hydrogen protons in the brain tissue, creating a magnetic field change

Functional Magnetic Resonance Imaging (fMRI) A method of magnetic resonance imaging that measures energy released by brain cells that are active during a specific task



(Shutterstock)

This computer screen shows a series of positron emission tomography (PET) scans. PET scans identify areas of the brain that are most active in response to a variety of tasks.

2.8 The Endocrine System

Up to this point in this chapter, we have covered only the nervous system. However, the nervous system is not the only biological system that governs behavior. To be complete, a discussion of biological foundations of behavior should also consider the role of the endocrine system, which is illustrated in Figure 2-14.

The **endocrine system** consists of several glands located throughout the body. Glands in the endocrine system are *ductless*; that is, they have no external excretory ducts but rather secrete internally directly into the bloodstream or lymph fluid. (The lymph system is a system of vessels and organs that makes up your immune system.) The major endocrine glands include the pituitary, the thyroid, the parathyroid, the adrenals, the pancreas, and the gonads. The location of the various endocrine glands is shown in Figure 2-14. Each of these glands produces **hormones**, which are secreted directly into the bloodstream. A single gland may produce several different hormones.

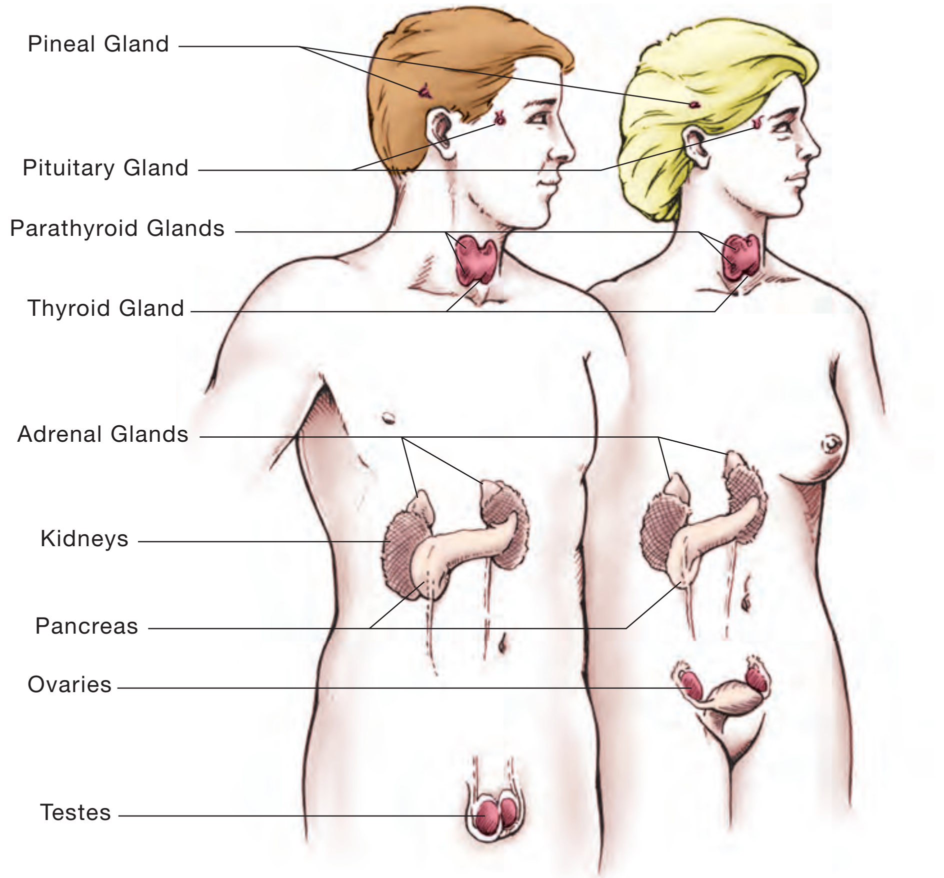
Like neurotransmitters, hormones act as chemical messengers. In fact, some important chemicals within the body can function as both neurotransmitters and hormones. Norepinephrine, for example, acts as a hormone when released by the adrenal glands and as a neurotransmitter when released by a neuron. There is, however, a key difference in the way these two classes of chemicals act. Because neurotransmitters only need to travel across a synaptic gap (a fraction of the distance that most hormones travel through the bloodstream), they have a much more immediate effect on behavior than that of chemicals in the endocrine system.

The endocrine system often works in tandem with the nervous system. For example, when a person is suddenly exposed to a fear-inducing stimulus, such as the bear in the earlier example, heart rate increases instantly in response to sympathetic nervous system input. At the same time, the adrenal glands secrete epinephrine, which has a similar effect on heart rate. In this fashion, the two major regulating systems of the body often work together.

Endocrine System System of ductless glands, including the pituitary, thyroid, parathyroid, adrenals, pancreas, and gonads, that secrete hormones directly into the bloodstream or lymph fluids

Hormones Chemical messengers secreted by the endocrine glands that act to regulate the functioning of specific organs

Figure 2-14 The Major Glands of the Endocrine System



The hypothalamus is a key interface between the nervous system and the endocrine system. As noted earlier, this region of the brain controls the activity of the pituitary gland through production of a group of chemicals known as *hypothalamic-releasing factors*. These chemicals, in turn, stimulate the pituitary to produce hormones that stimulate other glands.

Once an endocrine gland releases a hormone into the bloodstream, the substance travels throughout the body. However, each hormone exerts its primary influence only on certain specific organs and cells, often referred to as *target organs*. Some hormones, called *trophic hormones*, affect only the activity of another endocrine gland. For example, hormones called gonadotropins stimulate only the gonads.

Endocrine glands do not produce a steady stream of hormones. Instead, target organs signal the secreting glands either to increase or decrease secretions. Hormones are secreted until the target organ is stimulated; at this point, the target organ releases another substance that circulates back through the system to regulate hormonal activity in the initiating gland. This *negative-feedback mechanism* provides an internal control that limits extremes of hormone production.

Through these general mechanisms, the endocrine system influences many important physiological functions including metabolism, emotional responses, and motivation. A number of these effects are of particular interest to psychologists.

2.8a The Pituitary Gland

Located in the brain below the hypothalamus, the **pituitary gland** produces the largest number of different hormones, some of which trigger other glands to release other hormones. For this reason, the pituitary gland is sometimes called the master gland, but, as we have seen, it is actually controlled by the hypothalamus.

The pituitary also produces a number of huge protein molecules called neuropeptides, mentioned in our earlier discussion of endogenous opioids. Each neuropeptide consists of a long chain of amino acids that is broken down by enzyme action into various lengths of small chains. These substances act as neurotransmitters, and they influence a number of functions such as eating and drinking, sexual behavior, sleep, temperature regulation, pain, and responses to stress.

2.8b The Thyroid Gland

The **thyroid gland**, located within the neck, responds to pituitary stimulation by releasing the hormone **thyroxine**. This substance affects a number of biological functions, the most important of which is the regulation of metabolism (the transformation of food into energy). Because metabolism is in turn closely linked to motivational and mood states, the thyroid has an important impact on behavior. For example, if too little thyroxine is produced (a condition known as *hypothyroidism*), a person behaves in a lethargic manner, demonstrates little motivation to accomplish tasks, and often manifests symptoms of depression. Excessive thyroxine output (*hyperthyroidism*) may have just the opposite effect, causing hyperactivity, weight loss, anxiety, and excessive tension (Samuels, 2008). An undersecretion of thyroxine early in life produces *cretinism*, a condition characterized by low intelligence and various body defects such as dwarfed stature and dry, wrinkled skin. Fortunately, all of these conditions can be prevented or remedied by medical treatments.

2.8c The Adrenal Glands

The **adrenals** are a pair of glands, located just above each kidney, that influence our emotional state, level of energy, and ability to cope with stress. They consist of two distinct parts: an inner core called the *adrenal medulla* and an outer layer called the *adrenal cortex*. The adrenal medulla produces epinephrine and norepinephrine, both of which prepare the body to respond to emergencies by making the heart beat faster, diverting blood from the stomach and intestines to the voluntary muscles and enhancing energy resources by increasing blood sugar levels. The adrenal medulla is able to act quickly in threatening situations because it is stimulated directly by neural impulses.

As suggested earlier in the discussion of the peripheral nervous system, epinephrine and norepinephrine act in a way that is similar to the sympathetic nervous system. In fact, these hormones and the nervous system perform basically the same work. The sympathetic nervous system works more quickly, producing its effects almost instantly; yet the effects of the adrenal hormones can persist much longer. It is the lingering effects of hormones that explain why it often takes time for strong emotional arousal to subside after the cause for anxiety has been removed.

At times of stress, the hypothalamus causes the pituitary to release ACTH (*adrenocorticotropic hormone)*, which in turn stimulates the adrenal cortex to increase its secretion of a number of hormones that influence metabolism. The higher metabolic rate makes the stressed person more active, and therefore more able to cope with an emergency.

Pituitary Gland Gland in the endocrine system located directly below and connected to the hypothalamus; produces a number of hormones, many of which trigger other endocrine glands to release hormones

Thyroid Gland Endocrine gland located in the neck that influences metabolism, growth, and maturation; produces the hormone thyroxine

Thyroxine The major hormone produced by the thyroid gland that regulates metabolism

Adrenal Glands Glands within the endocrine system, located just above the kidneys, that release hormones to influence emotional state, energy levels, and responses to stress

Prolonged stress, however, can have a debilitating effect on the body, including the brain and the immune system. A chronic state of tension, nervousness, fear, or even panic can take a terrible toll on one's emotional and physical well-being. Furthermore, abnormally high metabolic rates deplete vital body resources, which over time can lead to exhaustion and increased susceptibility to illness. Stress-related problems and stress-management techniques are discussed in Chapter 8.

2.8d The Gonads

The **gonads**—ovaries in the female and testes in the male—produce several varieties of sex hormones. The ovaries produce two classes of hormones: the estrogens (the most important of which is estradiol), which influence development of female physical sex characteristics and regulation of the menstrual cycle; and the *progestational compounds* (the most important is progesterone), which help to regulate the menstrual cycle and prepare the uterus for pregnancy. As we mentioned earlier, estradiol also contributes to sex differences in the cerebral cortex and the hypothalamus.

The primary output of the testes is the *androgens*. The most important of these hormones is testosterone, the function of which is to influence the development of both male physical sex characteristics and sexual motivation. In both sexes, the adrenal glands also secrete sex hormones, including small amounts of estrogen and greater quantities of androgen (this is where females get testosterone).

Around the onset of puberty, the sex hormones play a critical role in initiating changes in the primary sexual systems (the growth of the uterus, vagina, penis, and so forth) and the secondary sex characteristics, including body hair, breast development, and voice changes. They also exert strong influences on the fertility cycle in women, and they seem to contribute to sexual motivation. Chapter 7 discusses the relationship of sex hormones to sexual motivation in more detail.

2.9 Drugs and Behavior

A wide variety of commonly used drugs have the effect of changing thought processes, emotional states, and behavior. Solomon Snyder (1984), an expert on neurotransmitters, stated, "Virtually every drug that alters mental function does so by interacting with a neurotransmitter system in the brain" (p. 23). This interaction may happen in a variety of ways. Some drugs increase neural activity by releasing neurotransmitters from the presynaptic vesicles; some actually mimic certain excitatory transmitters. Other drugs may prevent transmission of neural impulses by binding or attaching themselves to receptors on the postsynaptic membrane, thus preventing the kind of contact between excitatory transmitters and postsynaptic receptors that is necessary to trigger EPSPs. Still other drugs interfere with the reuptake of intact chemicals or the recycling of their breakdown products. In this section we examine some of the more common drugs used to alter behavior.

It is not uncommon for people in our society to have a few glasses of wine at a party and then to follow through the next morning with a few cups of coffee or tea to help clear the cobwebs. Most of us regularly consume a variety of chemicals (such as alcohol and caffeine) that alter our perceptions and behavior. Such substances, as well as nicotine, marijuana, sleeping pills, cocaine, and narcotics, are called psychoactive drugs.

Continued use of many of the psychoactive drugs tends to lessen their effects, so that the user develops a **tolerance** to the drug. For example, repeated injections of

Gonads Glands within the endocrine system (ovaries in females and testes in males) that produce sex hormones that influence development of sexual systems and secondary sex characteristics, as well as sexual motivation

Tolerance A decrease in the effectiveness of a drug observed after repeated administration opiates, such as heroin, result in the development of tolerance, which means that the user must continually increase the amount of drug taken to get euphoric effects. Along with tolerance, physiological **dependence** on the drug may also develop over time. If a person becomes drug *dependent*, withdrawal symptoms such as cramps, nausea, tremors, headaches, and sweating occur in the drug's absence. In some cases a severe form of dependence called **addiction** may occur. Addiction is a brain disease caused by repeated administration of drugs that rapidly increase dopamine activity. Excessive dopamine activity results in structural and functional changes to the mesolimbic system and the frontal cortex. For example, drugs such as alcohol, cocaine, amphetamines, and opiates are all powerfully addictive (Ettinger, 2017). One of the most ironic things about drug addiction is that the original reason for taking the drug (for example, to relieve pain) may be replaced by a desperate need to maintain adequate levels of the drug just to avoid withdrawal symptoms. We will see in Chapter 5 that tolerance to opiate drugs is a learned response and contexts surrounding drug use are important cues to its development.

The three major groups of drugs, classified by their effects, are depressants, stimulants, and hallucinogens. The remainder of this chapter looks at these types of drugs and their effects on people.

2.9a Depressants: Sedatives, Opiates, and Alcohol

Drugs that tend to slow or depress activity in the central nervous system are classified as **depressants**. Substances in this category include sedatives, opiates, and alcohol.

Sedatives

Sedatives are drugs that induce relaxation, calmness, and sleep. This group of drugs includes *barbiturates,* such as Phenobarbital® and Seconal®; and the *benzodiazepines*, including Valium and Xanax®. Many of these drugs are widely prescribed by physicians as remedies for emotional and physical complaints such as anxiety, insomnia, gastrointestinal disorders, and respiratory problems. Chapter 13 discusses some of these drugs and their uses for treating psychological disorders.

All the sedative drugs, particularly barbiturates (also known as barbs or downers), are prime candidates for drug abuse. Tolerance for barbiturates develops quite rapidly, and abusers of these drugs often increase their consumption to the point at which respiratory function, memory, judgment, and other mental and physical processes are seriously impaired. Because barbiturates can be particularly lethal after an overdose, these drugs are becoming less frequently prescribed. The effects of sedative and depressant drugs such as alcohol, barbiturates, and benzodiazepines taken in combination can be lethal. For instance, combining a nonlethal dose of alcohol with a nonlethal dose of barbiturates can cause death (Gillett & Warburton, 1970).

Virtually every drug that alters behavior does so by interacting with a neurotransmitter system in the brain. The sedative drugs are no exception. The mechanisms whereby they accomplish their effects are well understood. For example, it is known that sedative drugs increase the sensitivity of postsynaptic receptors for GABA, an important neurotransmitter that acts to inhibit neural transmission (L. Richter et al., 2012). By increasing the inhibition generated by GABA, the sedative drugs reduce neural activity in the brain circuits, including the frontal cortex and the amygdala, involved with emotional arousal.

Dependence Physiological adaptation to repeated drug administration that can lead to withdrawal symptoms upon cessation of drug use

Addiction A brain disease caused by repeated administration of drugs that rapidly increase dopamine activity, resulting in structural and functional changes to the mesolimbic system and frontal cortex (Not all drugs that cause dependence necessarily cause addiction.)

Depressants Psychoactive drugs, including opiates, sedatives, and alcohol, that have the effect of slowing down or depressing central nervous system activity

Sedatives Class of depressant drugs, including tranquilizers, barbiturates, and benzodiazepines, that induce relaxation, calmness, and sleep

Opiates

Opiates or **narcotics** are another category of depressant drugs. *Opium* is derived from a sticky resin secreted by the opium poppy. Two of its natural ingredients, *morphine* and *codeine*, have been widely used as painkillers. A third derivative, *heroin*, is obtained by chemically modifying morphine.

Heroin is snorted (inhaled through the nostrils) or injected directly into the veins. When it is injected, the almost immediate effect is a rush, which users describe as an overwhelming sensation of pleasure akin to sexual orgasm. This rush may be the closest many heroin addicts come to sexual orgasm, however, as regular use of opiates often significantly decreases sexual interest and activity. Shortly after it is injected, heroin decomposes into morphine, which produces other effects commonly associated with opiate usage: a sense of well-being, contentment, and drowsiness.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The mortality rate among narcotics addicts is about seven times greater than among the general population.

However, increasingly larger doses of heroin are needed to produce these effects, and the user quickly acquires tolerance and dependence. The long-term effects of this dependence can be devastating. People addicted to heroin do almost anything to ensure their supply of the drug—cheat, steal, or prostitute themselves.

What happens when a heroin addict tries to break the habit? After a few hours without heroin, the user begins to experience withdrawal symptoms such as vomiting, runny nose, aching muscles, and abdominal pain. Intense drug cravings associated with abstinence often result in relapse to drug use again.

Opiates themselves produce little physical damage to the user. Chronic opiate use may damage the body's immune system, thus increasing the addict's susceptibility to disease. Research indicates that the mortality rate among narcotics addicts is approximately seven times greater than that of the general population. There are a variety of reasons for this statistic. Addicts often cause harm to themselves through drug-related habits, such as using nonsterile needles, obtaining contaminated heroin, or not eating properly. Carelessness about using sterile drug paraphernalia increases the risk of potentially life-threatening infectious diseases such as AIDS, hepatitis (a liver infection), and endocarditis (inflammation of a membrane in the heart) (Wang, Zhang, & Ho, 2011). The incidence of opiate abuse has dramatically increased over the past ten years. In 2014, more than 28,000 people died from prescription opiates and heroin. This represents seventy-eight American deaths each day. The drastic increase in opiate deaths coincides with a significant increase in prescription sales. Enough opiates are produced each year to provide every U.S. citizen a dose every four hours (twenty-four hours a day) for a month (Chen, 2016).

Alcohol

Like other depressants, alcohol retards the activity of neurons in the central nervous system, particularly in the cerebral cortex and the cerebellum, by increasing the sensitivity of postsynaptic GABA receptors (Wallner & Olsen, 2008). It is an extremely potent drug that affects behavior in a highly variable manner. Some people become more communicative and expressive under its influence, perhaps even boisterous and silly. Others become

Narcotics (Opiates) A class of depressant drugs that includes opium, morphine, codeine, and heroin aggressive, abusive, and sometimes violent. People under the influence of alcohol may engage in behaviors they normally keep in check, probably because alcohol suppresses the inhibitory mechanisms of the cerebral cortex.

These behavioral effects may be evident at relatively low levels of alcohol consumption. As intake increases, it is accompanied by more pronounced impairments of coordination, reaction time, thinking, and judgment. When blood alcohol content reaches 0.10 percent (the equivalent of four to six beers or three to four 1.5-ounce shots of 80-proof alcohol), a person's chance of having a severe accident behind the wheel of a car or otherwise may be as much as five or six times greater than normal. In most states, the legal limit for blood alcohol levels is 0.08.

Prolonged and excessive use of alcohol can lead to addiction and have disastrous physical effects. Liver and heart disease are commonly associated with alcohol abuse. Malnutrition is also a problem because excessive drinkers typically eat poorly since their daily consumption of liquor provides hundreds of calories. In addition, alcohol interferes with the proper absorption of B vitamins, so vitamin B deficiency is common. A prolonged deficiency of these essential vitamins can lead to brain damage, a complication that occurs in about 10 percent of alcoholics. Alcoholic brain damage, which can include cerebral and cortical atrophy and reduced brain weight, has been associated with a variety of cognitive and behavioral impairments. Alcoholics also tend to develop various kinds of infections at a rate higher than normal—due in part to alcohol's immune-suppressing effects (Friedman, Newton, & Klein, 2003; Hote et al., 2008). The National Institute on Alcohol Abuse and Alcoholism estimated that there are more than seventeen million (one in twelve) alcohol addicts in the United States, and many of them are not receiving adequate treatment (Alcohol Facts and Statistics, 2017). It is further estimated that alcohol abuse affects one in four households.

Heavy drinking during pregnancy causes further complications. Because alcohol passes from the mother's body to the fetus, the infant may be born with an alcohol addiction. Drug withdrawal in a baby can be fatal. Offspring of mothers who drink heavily while they are pregnant may suffer from *fetal alcohol syndrome*, which is characterized by retarded physical growth, intellectual development, and motor coordination as well as abnormalities in brain metabolic processes and liver functioning.

2.9b Stimulants: Caffeine, Nicotine, Amphetamines, and Cocaine

Drugs that stimulate the central nervous system by increasing neural transmission are called **stimulants**. The most widely consumed of these drugs are caffeine and nicotine, both of which are mild stimulants. Amphetamines and cocaine are the most frequently used of the stronger stimulants.

Caffeine

Found in a variety of products—including chocolate, coffee, tea, and many carbonated soft drinks such as colas—caffeine has long provided people with a quick lift. Caffeine acts quickly. Within a few minutes after caffeine is consumed, heart and respiration rates and blood pressure increase.

People experience these physical effects in a variety of ways. Most feel mentally stimulated; some experience a brief burst of energy. People who consume a large amount of caffeine (for example, six or more cups of coffee) may feel more pronounced effects:

Stimulants Psychoactive drugs, including caffeine, nicotine, amphetamines, and cocaine, that stimulate the central nervous system by increasing the transmission of neural impulses


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Caffeine is a stimulant that works by blocking adenosine receptors in the nervous system.

irritability, headaches, the jitters, difficulty concentrating, nausea, and sleep disturbances. People can become dependent on caffeine, as evidenced by the countless numbers of people who just cannot function without their daily quota of coffee, tea, or cola.

Caffeine exerts its effects on the nervous system by blocking adenosine receptors. Adenosine is an inhibitory neurotransmitter that produces behavioral sedation and regulates the dilation of blood vessels (Ettinger, 2017).

Nicotine

Nicotine is second only to caffeine on the list of widely used stimulants. Found in tobacco, nicotine increases heart rate, blood pressure, and stomach activity, and constricts blood vessels. Paradoxically, it may have either a relaxing or a stimulating effect on the user, depending on the circumstances and the user's expectations. Nicotine is addictive, and people who stop smoking may experience a variety of withdrawal symptoms including craving for tobacco, increased appetite, stomach cramps, headaches, restlessness, irritability, insomnia, anxiety, and depression.

The long-term effects of smoking have been well publicized. More than five hundred thousand people die every year from coronary heart disease, cancer, respiratory diseases, and other diseases caused by smoking. There is also evidence that women who smoke while pregnant have a higher incidence of miscarriages, stillbirths, low-birth-weight babies, and babies who die from sudden infant death syndrome (SIDS) than women who do not smoke (Shea & Steiner, 2008; Zotti, Replogle, & Sappenfield, 2003).

Amphetamines

Amphetamines are much more powerful stimulants, sold under the trade names Adderall® and Dexedrine® and known on the street as methamphetamine, which is a slightly altered version of amphetamine. These drugs tend to dramatically increase alertness and activity, counteract fatigue, and promote feelings of euphoria and well-being. These effects are most likely caused by the influence of amphetamine on both norepinephrine- and dopamine-containing neurons. Amphetamines increase the activity of these neurotransmitters by increasing the amount released from the nerve terminal and by preventing their reuptake (Ettinger, 2017)

People use amphetamines for a variety of reasons: to stay awake, to feel good, to improve energy levels, to increase confidence, and to lose weight (amphetamines are short-term appetite suppressants). Most users take the drug orally, but some inject it directly into a vein. When amphetamines are used in excess, they can cause muscle and joint aches, tremors, and feelings of paranoia. In extreme cases, amphetamines produce both punding, which is a repetitive motor response, and *amphetamine psychosis*, which combines paranoia with hallucinations and difficulty recognizing people. Methamphetamine addiction has become a major problem in many areas of the country.

Amphetamines A group of powerful stimulants, including Benzedrine, Dexedrine, and Ritalin®, that dramatically increase alertness and promote feelings of euphoria

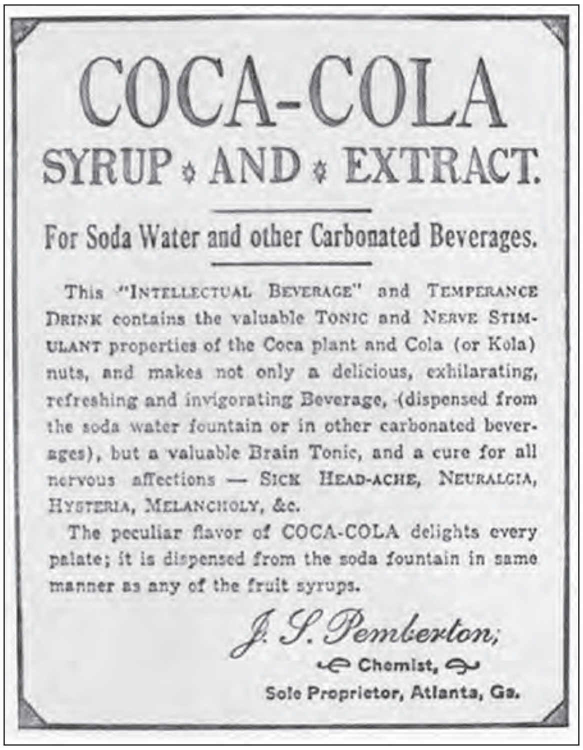
Cocaine

Cocaine is a powerful central nervous system stimulant that is extracted from leaves of the coca shrub. It is often sniffed (snorted) through a straw into the mucous membranes of the nasal passages. A solution of the drug may also be injected into the vein. Crack is the street name given to cocaine that has been processed from cocaine hydrochloride (the crystalline derivative of the coca leaf that is sold on the street as coke) into freebase by using ammonia or baking soda and water, and heating the mixture. (The baking soda causes a crackling sound when the base is heated, thus giving rise to the street name.)

No matter which form is used, many of cocaine's effects are similar to those of amphetamines. They include increased alertness and abundance of energy, feelings of euphoria, and a sense of well-being. Cocaine increases heart and respiration rates, constricts blood vessels, and dilates the pupils. It is metabolized very quickly, so its effects often last only twenty to thirty minutes. Thus, to maintain a high, the user must take the drug frequently—one reason why a cocaine habit can become very costly.

Like other drugs, cocaine seems to derive its effects by altering normal patterns of dopamine activity, primarily in the mesolimbic cortical system (the brain's reward system). There is good evidence that cocaine blocks the reuptake of dopamine and norepinephrine, increasing the time these chemicals actively stimulate their receptors.

Cocaine is perhaps the most powerfully addictive substance we know. Its abuse can lead to severe problems, including heart and lung damage, anemia, damage to the nasal tissues, immune system impairment, and, in rare cases, sudden death. Despite these facts, cocaine use continues to be problematic in the United States. In 2010, surveys revealed that more than forty-two million Americans had used some form of cocaine and about 2,700 people try it for the first time each day. About 8 percent of high school seniors report having tried cocaine at least one time (National Institute on Drug Abuse, 2010). Although there is no known cure for cocaine addiction, research in the author's laboratory has resulted in a cocaine vaccine. Rats vaccinated with the cocaine antibody preparation became resistant to cocaine's reinforcing and analgesic effects (Johnson & Ettinger, 2000; R. Ettinger, W. Ettinger, & Harless, 1997). Whether or not an anticocaine vaccine will become available to treat cocaine addicts remains to be seen.



(Wikimedia Commons/Public Domain)

When Coca-Cola® first appeared on the market in 1885, it contained cocaine. Cocaine was removed from soft drinks in 1903.

2.9c Hallucinogens: LSD and Ecstasy

LSD

Derived from the ergot fungus that grows on rye grass, **LSD (lysergic acid diethylamide)** became recognized for its psychoactive properties in the 1940s. Throughout the 1950s and early 1960s, researchers experimented with it as a tool for treating behavioral and emotional disorders, as a pain reliever for people suffering from terminal disease, and as a drug that might have possible military applications. Eventually, LSD fell into disrepute, largely because of its unpredictable effects. However, this official disfavor did not curtail

LSD (Lysergic Acid Diethylamide) Hallucinogenic drug derived from a fungus that grows on rye grass that produces profound distortions of sensations, feelings, time, and thought

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its growing popularity as a street drug used to alter and expand consciousness. In recent years, LSD's popularity has somewhat resurged, particularly among high school students. In 1997, 14 percent of high school seniors reported that they had experimented with LSD use at least once. This number has steadily decreased to about 3 percent (National Institute on Drug Abuse, 2016).

LSD is one of the most powerful known **hallucinogens**. A tiny amount can produce profound distortions of sensations, feelings, perception of time, and thought. Some users describe an LSD trip as spiritual, mind expanding, and a source of ecstasy. Some claim that the drug adds to their creativity, but this assertion is unfounded. Others have painful, frightening experiences in which they may feel that they have lost control, that their bodies are undergoing change, or that they have left their body behind. Having a good LSD experience one time is no guarantee that the next LSD experience will not turn into a nightmare.

Brain researchers are still not sure how drugs such as LSD produce hallucinogenic effects, but they theorize that hallucinations result from the disruption of the neural circuits responsible for filtering sensory information. Normally, serotonin modulates awareness by filtering a large proportion of sensory and somatosensory information that is unnecessary for normal functioning. LSD appears to open these filters so an increased amount of sensory information is processed (González-Maeso et al., 2007).

Ecstasy

Ecstasy, or MDMA, is a much less powerful hallucinogenic drug than LSD, and some researchers do not even classify it as such. However, ecstasy is known to produce both bodily and visual distortions in some users. The most prominent effects of ecstasy are mood enhancement and a profound sense of well-being. Users may also experience a sense of depersonalization and thought disturbances. Ecstasy exerts these effects by causing the release of large amounts of serotonin. By releasing large amounts of serotonin, and also interfering with its synthesis, ecstasy leads to serotonin depletion. As a result, it takes the human brain a significant amount of time to rebuild the store of serotonin needed to perform important physiological and psychological functions. Not all of ecstasy's effects, however, are as desirable as these. Users commonly experience hyperthermia, rapid heart rate, high blood pressure, muscle rigidity, and convulsions. Of the recreational drugs discussed here, ecstasy is by far the most toxic to the nervous system and repeated use appears to irreversibly destroy serotonin-containing neurons (National Institute on Drug Abuse, 2016). Fortunately, the use of ecstasy has declined over recent years from 8.3 percent of high school seniors in 2003 to about 5 percent in 2014.

2.9d Marijuana

Marijuana

As a recreational drug, **marijuana** is the most widely used of the illegal psychoactive drugs, second in popularity only to alcohol. Marijuana use appears to have leveled off since its all-time high in 1997, when it was estimated that 50 percent of twelfth graders had used marijuana. In 2015, more than two million Americans had tried marijuana, and 45 percent of twelfth graders had used it at least once (National Institute on Drug Abuse, 2016).

Marijuana is derived from the flowering top of the *Cannabis sativa*, a hemp plant once known primarily as an excellent material for making ropes. The mind-altering component of marijuana is the chemical THC (delta 9-tetrahydrocannabinol).

Hallucinogens Class of psychoactive drugs, including LSD and ecstasy, that alter sensory perceptions, thinking processes, and emotions, often causing delusions, hallucinations, and an altered sense of time and space

Marijuana Drug derived from the hemp plant *Cannabis sativa*, containing the chemical THC (delta 9-tetrahydrocannbinol)

Until recently, researchers did not know how marijuana altered the activity of the brain to produce its euphoric effects. However, William Devane and his coworkers have recently identified receptors for THC in the brain, as well as a natural substance that binds with these THC receptors. The brain's natural THC has been named **anandamide**, meaning bliss (Devane et al., 1992). It is now believed that anandamide plays an important role in regulating mood, pain, movement, and appetite.


(Shutterstock)

Marijuana has been found to have medicinal qualities, although the controversy surrounding its legalization in the United States is likely to continue for some time.

Two physiological effects of marijuana use are increased heart rate and enhanced appetite. Small doses often produce euphoria and enhance some sensory experiences, such as listening to music. Marijuana impairs reaction time and the ability to concentrate on complex tasks, and some people become confused, agitated, or extremely anxious under its influence. Marijuana impairs a person's perceptual skills and motor coordination, thus significantly increasing the risk of having an accident while driving an automobile. Recall may also be impaired while under the influence of marijuana. There are few if any long-term effects of marijuana use.

Medical practitioners have discovered that marijuana can be therapeutic in some situations. For example, it can be helpful to those with epilepsy and glaucoma (a disease that can cause blindness). It has been shown to reduce the nausea that often accompanies chemotherapy treatment for cancer patients, and it may now be used to prevent some of the weight loss associated with AIDS diseases. Because of these legitimate medical uses, marijuana is legally obtained for these purposes in some states. Controversy still surrounds the issue of marijuana legalization in the United States and is likely to continue for some time. Several states have legalized marijuana for recreational use, including Washington, Colorado, Alaska, and Oregon. Other states are considering legalization, and this trend is expected to continue.

Anandamide A naturally occurring substance that binds to THC receptors in the brain (Marijuana contains THC, which also binds to these receptors.)

CHAPTER REVIEW

Overview of the Nervous System: Organization and Function

1. The nervous system of humans and other vertebrates consists of two major parts: the central nervous system (CNS) and the peripheral nervous system (PNS).
2. The CNS consists of the brain and the spinal cord. It occupies the commanding position in the nervous system, as it coordinates and integrates all bodily functions.
3. The PNS transmits messages to and from the CNS. It is subdivided into the somatic nervous system and the autonomic nervous system.

Neurons: Basic Units of the Nervous System

4. There are three major classes of neurons: sensory neurons that carry messages to the CNS; motor neurons that transmit messages from the CNS to muscles and glands; and interneurons that act as intermediaries between sensory and motor neurons.
5. Neurons have four common structures: the cell body, which handles metabolic functions; the dendrites, which receive neural messages; the axon, which conducts a message to the end of the neuron; and the terminal buttons at the end of the axon, which release transmitter substances.
6. The transmission of a neural message involves both electrical and chemical aspects. Electrical processes are activated when the dendrites (or cell body) of a neuron respond to an impulse from neighboring neurons by undergoing a change in permeability of the cell membrane. Voltage changes then occur due to an influx of positive sodium ions through the more permeable membrane. These voltage changes are called graded potentials. When the sum of graded potentials reaches a sufficient magnitude, an electrical signal or action potential is generated that flows along the length of the neuron.
7. Neural impulses are transmitted from one neuron to another, across the synaptic gap, via chemical messengers called neurotransmitters. These transmitter substances may act either to excite or inhibit action potentials in the receiving neuron.
8. Variations in neurotransmitter levels, or in responsiveness to these chemical messengers, have been linked with various psychological disorders and the action of numerous drugs.
9. Endogenous opioids, which are part of a family of neurotransmitters known as neuropeptides, have been linked to a range of behavioral and mental processes, including inducing euphoria, counteracting stress, modulating food and liquid intake, facilitating learning and memory, and reducing pain.

CHAPTER REVIEW

The Peripheral Nervous System

10. The PNS, which transfers information to and from the CNS, has two divisions: somatic and autonomic.
11. The somatic nervous system serves the major skeletal muscles that carry out intentional movements. It also contains nerves that transmit sensory information from the skin, muscles, and sensory organs of the body.
12. The autonomic nervous system controls the glands and smooth muscles of internal organs. The two subdivisions of the autonomic nervous system, the sympathetic and parasympathetic systems, operate in an integrative fashion to allow the body to function optimally when either relaxed or highly aroused. The sympathetic system is particularly active during emotional emergencies. The parasympathetic system, which provides a braking mechanism for organs activated by the sympathetic system, is more involved during relaxation and body restoration.

The Central Nervous System

13. The spinal cord conveys messages to and from the brain, helps coordinate the two sides of the body, and mediates certain basic reflexive behaviors (such as the quick withdrawal of a hand from a hot stove).
14. The medulla, the lowest part of the brain, contains centers that control many vital life-support functions such as breathing, heartbeat, and blood pressure.
15. The pons, a large bulge in the lower brain core, plays a role in fine-tuning motor messages and in processing some sensory information.
16. The cerebellum, tucked beneath the back part of the cerebral hemispheres, coordinates and regulates motor movements.
17. The reticular formation or reticular activating system, a set of neural circuits extending from the lower brain up to the thalamus, plays a role in controlling levels of arousal and alertness.

Lymbic System

18. The limbic system, a collection of structures located around the central core of the brain, is closely associated with emotional expression. It also is active in motivation, learning, and memory.
19. The hypothalamus, located beneath the thalamus, helps to maintain homeostasis within the body's internal environment. In addition, it plays a key role in controlling emotional expression and serves as the hub of the neuroendocrine system.
20. The thalamus, located beneath the cerebral cortex, plays a role in routing incoming sensory information to appropriate areas within the cerebral cortex.

CHAPTER REVIEW

Basal Ganglia

21. The basal ganglia consists of several structures involved in motor movement, including the caudate nucleus, putamen, and substantia nigra.

The Cerebral Cortex

22. The cerebral cortex, the thin outer layer of the cortex, is the part of the brain responsible for higher mental processes such as perceiving, thinking, and remembering.
23. To some degree, researchers have been able to localize a variety of functions within various regions or lobes of the cortex of the two hemispheres. The frontal lobe contains the motor cortex, a narrow strip of brain tissue that controls a wide range of intentional body movements. The primary brain center for controlling speech is also in the frontal lobe. The parietal lobe contains the somatosensory cortex, which receives sensory information about touch, pressure, pain, temperature, and body position from various areas of the body. The occipital lobe consists primarily of the visual cortex, devoted to the business of seeing. Hearing, a primary function of the temporal lobe is localized in the auditory cortex.
24. Split-brain research, in which the primary connection between the two hemispheres (the corpus callosum) is severed, has revealed important information about the degree to which a particular function is controlled by one rather than both hemispheres (lateralization of function). This research has supported the interpretation that in most people the left hemisphere is primarily responsible for language and speech, logic, and mathematics. In contrast, the right hemisphere appears to be more important in perceiving spatial relationships, manipulating objects, synthesizing (generalizing the whole from segments), and artistic functions.
25. A number of techniques are employed to study the brain: lesion production, brain stimulation and electrical recording via implanted wires, electroencephalography (EEG), computerized axial tomography (CAT), positron emission tomography (PET), and magnetic resonance imaging (MRI) and fMRI.

The Endocrine System

26. The endocrine system is composed of several ductless glands that secrete hormones directly into the bloodstream. The endocrine system often works in tandem with the nervous system to regulate a variety of bodily responses. The hypothalamus functions as a key interface between the nervous system and the endocrine system.
27. The endocrine system influences many important physiological functions, mental processes, and behavior patterns, including disease regulation, metabolism, emotional responses, and motivation.

28. The pituitary gland produces hormones that trigger other glands to action. Among other important products of the pituitary are growth hormones, which control a number of metabolic functions including the rate of growth, and neuropeptides, which act as neurotransmitters that influence such things as eating and drinking, sexual behavior, sleep, pain reduction, and responses to stress.
29. The thyroid gland produces thyroxine, which helps to regulate metabolism. Lethargy and hyperactivity are related to too little or too much thyroxine, respectively.
30. The paired adrenal glands produce a variety of hormones, including epinephrine and norepinephrine, which prepare the body to respond to emergencies and cope with stress.
31. The gonads secrete several varieties of sex hormones that influence development of physical sex characteristics, sexual reproduction, and sexual motivation.

Drugs and Behavior

32. Sedative drugs, such as barbiturates, induce relaxation and sleep. They are often prescribed for anxiety and sleep disorders.
33. Opiates or narcotics such as morphine and heroin induce a state of euphoria and are highly addictive. The opiates (such as Vicodin® and Oxycodone®) are often prescribed to control pain.
34. Alcohol acts as a central nervous system depressant in the cerebral cortex and cerebellum. Alcohol is the nation's number one drug problem.
35. The major stimulants include caffeine, nicotine, amphetamines, and cocaine.
36. Amphetamines and cocaine are powerful stimulants that are highly addictive.
37. The hallucinogens, such as LSD and ecstasy, produce changes in perception and emotions.
38. Marijuana has few, if any, long-term effects on cognition, but it does disrupt cognitive functioning (including memory) when a person is under its influence. A number of states have legalized marijuana for medical purposes.

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POP QUIZ

True or False

___ 1. The terminal buttons of one neuron secrete neurotransmitter into the synapse where it stimulates the axon of a second neuron.

___ 2. Neurotransmitters may have either an excitatory or inhibitory effect on the postsynaptic membrane.

___ 3. During the body's response to an emergency situation, the parasympathetic nervous system resumes control of bodily functions such as heart rate and digestion.

___ 4. The cerebellum is the brain structure responsible for higher mental processes such as perceiving, thinking, and remembering.

___ 5. Marijuana may have a sedative effect, stimulant effect, or an antidepressant effect.

Multiple Choice

6. Which is the last part of the neuron to be involved in the transmission of a neural impulse toward the next neuron?
   a. Axon hillock
   b. Cell body
   c. Dendrites
   d. Terminal button
7. Two factors that relate to the perceived intensity of a stimulus are how many neurons are firing action potentials and ______.
   a. if the axons have myelin sheaths
   b. the voltage associated with each action potential
   c. the rate at which these neurons are firing
   d. whether the supply of neurotransmitter is exhausted
8. The two major divisions of the peripheral nervous system are which of the following?
   a. Afferent and efferent
   b. Sympathetic and parasympathetic
   c. Somatic and parasympathetic
   d. Somatic and autonomic
9. A major difference between the sympathetic and parasympathetic nervous systems is that the sympathetic nervous system provides which function?
   a. Increases the level of functioning in all the affected bodily systems
   b. Decreases the level of functioning in all the affected bodily systems
   c. Stimulates the different parts of the body independently of one another
   d. Simultaneously stimulates the different parts of the body

POP QUIZ

10. Which role does the reticular formation play?
    a. Life-supporting functions such as breathing and heartbeat
    b. The fine-tuning of motor messages
    c. Coordinating and regulating motor movements
    d. Controlling levels of arousal and alertness
11. If you were to electrically stimulate a person's occipital lobe, that person would most likely have which of the following reactions?
    a. Have difficulty recalling their phone number
    b. Report a visual experience
    c. Move a part of their body
    d. Report an auditory experience
12. If a split-brain patient sees "air x plane" briefly while focusing on the "x," the patient would say that he or she saw which of the following words?
    a. Plane
    b. Airplane
    c. Air
    d. That patient would report that he or she did not see a word.
13. The pituitary hormones do which of the following?
    a. Have a variety of target organs
    b. Have the thyroid as their only target organ
    c. Directly influence the hypothalamus to begin secreting hormones
    d. Become neuropeptides
14. What are the three major types of psychoactive drugs?
    a. Sedatives, opiates, and hallucinogens
    b. Depressants, amphetamines, and cocaine
    c. Depressants, stimulants, and hallucinogens
    d. Alcohol, opiates, and hallucinogens
15. A person admitted to a hospital following a drug use is experiencing hyperthermia, rapid heart rate, high blood pressure, muscle rigidity, and convulsions. Most likely he took which one of the following drugs?
    a. Seconal
    b. Heroin
    c. Ecstasy
    d. Cocaine

Answer Key: 1. F 2. T 3. F 4. F 5. F 6. d 7. c 8. d 9. d 10. d 11. b 12. a 13. a 14. c 15. c